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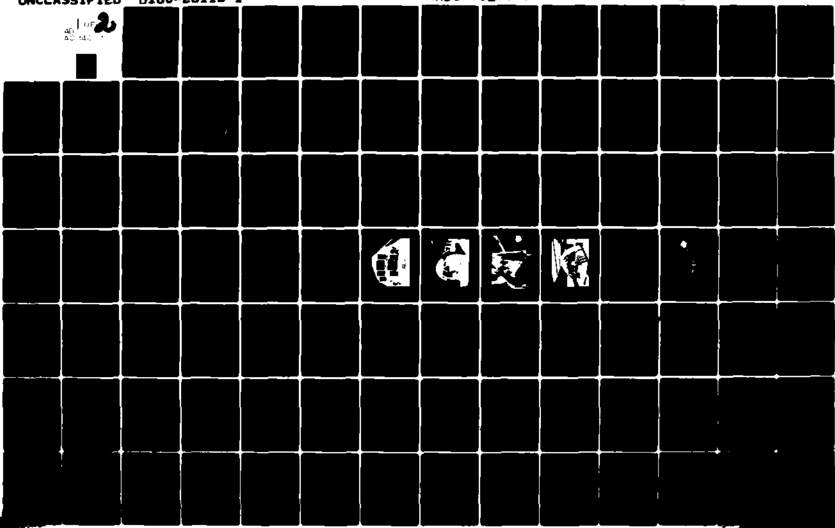

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USER'S GUIDE FOR THE DESIGN SECTIONS OF MIL-H-46855

BOEING Aerospace Company
Engineering Technology
Seattle, Washington 98124

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September 26, 1980

Prepared for
Naval Air Development Center
Warminster, Pennsylvania 18974

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Final Report

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Explains how to implement the design sections of MIL-H-46855, Human Engineering Requirements for Military Systems, Equipment and Facilities. Written for Navy and contractor Human Factors Engineering (HFE) specialists. Cites DoD and Navy requirements for performing HFE design during system acquisition. Describes 8 standard HFE design techniques and 9 design techniques using computers. Explains when and how techniques are used, their products and purpose, and advantages and limitations.

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PREFACE

This user's guide was produced under Naval Air Development Center Contract No. N62269-76-C-0740 between 27 September 1979 and 26 September 1980. The guide is for use primarily during the design phase of system acquisition. It is for Navy and contractor Human Factors Engineering specialists. The subject of the guide is the design sections of MIL-H-46855, Human Engineering Requirements for Military Systems, Equipment and Facilities. Two other user's guides cover the analysis sections of MIL-H-46855 and the test and evaluation sections of MIL-H-46855.

The following persons provided guidance and contributions:

1. Cdr. Patrick M. Curran, Naval Air Development Center
2. Cdr. Norman E. Lane, Naval Air Development Center

Within the Boeing Company, the program was directed by W. J. Hebenstreit of Engineering Technology's Crew Systems Organization, Boeing Aerospace Company. Much of the information in the guide is derived from the previous work of C. W. Geer. The Human Factors Engineering expertise of Crew Systems personnel contributed to the contents of this document, especially F. E. Crowell, J. M. Booth, D. E. Rees, and G. A. Holcomb. R. E. Edwards of Boeing Computer Systems also contributed.

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1.0 INTRODUCTION

This document is one of a series of documents for managers and Human Factors Engineering (HFE) specialists about MIL-H-46855 (Reference 1). MIL-H-46855 contains human engineering requirements for analysis, design, and test and evaluation during system acquisition.

In addition to this guide for HFE specialists to the design sections of MIL-H-46855, there are guides for the HFE specialist to:

1) the analysis sections of MIL-H-46855 (Reference 2)

2) the test and evaluation sections of MIL-H-46855 (Reference 3).

There are also guides for managers to:

1) the analysis sections of MIL-H-46855 (Reference 4)

2) the design sections of MIL-H-46855 (Reference 5)

3) the test and evaluation sections of MIL-H-46855 (Reference 6).

1.1 Purpose of the Guide

MIL-H-46855 states the human engineering design requirements but does not specify how or when to implement them. This guide provides a single source of information for both Navy and contractor HFE specialists on implementation techniques and when they use them. HFE design techniques are described in a sufficient level of detail to enable the contractor HFE

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1. MIL-H-46855A, Human Engineering Requirements for Military Systems, Equipment and Facilities, 4 May 1972.
2. Geer, C. W., Analyst's Guide for the Analysis Sections of MIL-H-46855, D180-19476-1, Boeing Aerospace Company (BAC), Naval Air Development Center (NADC), Warminster, Pa., 30 June 1976.
3. Geer, C. W., User's Guide for the Test and Evaluation Sections of MIL-H-46855, D194-10006-1, BAC, NADC, 30 June 1977.
4. Geer, C. W., Navy Manager's Guide for the Analysis Sections of MIL-H-46855, D180-19476-2, BAC, NADC, 30 June 1976.
5. English, M., Navy Manager's Guide for the Design Sections of MIL-H-46855, NADC-79219-60, BAC, NADC, 26 September 1980.
6. Geer, C. W., Navy Manager's Guide for the Test and Evaluation Sections of MIL-H-46855, D194-10006-2, BAC, NADC, 30 June 1977.

specialist to apply the appropriate techniques for a specific system and to enable the Navy HFE specialist to monitor the contractor's efforts.

1.2 Scope of the Guide

As background, the guide briefly describes the HFE design process and the military standards and specifications which require that this process be performed during system acquisition. The major portion of the guide consists of detailed descriptions of the standard design techniques which have proved useful to HFE specialists for a number of years. Newer techniques using computers are also described. The purpose of each technique is explained. When and how the technique is used is described, and its advantages and limitations are mentioned. Examples of techniques are presented. Although actual figures are not given, techniques are compared in terms of relative length of time to perform, relative cost, and relative cost effectiveness.

These technique selection criteria are provided so that the contractor HFE specialist can choose appropriate design techniques for a specific program and develop realistic plans for the design portion of the program which are within budget and schedule constraints. The Navy HFE specialist in turn can monitor selection of these techniques for appropriateness.

This guide will be of use to the Navy HFE specialist in preparing Requests for Proposal, System Specifications, and contractors' Statements of Work; in selecting Data Item Descriptions for inclusion in the Contract Data Requirements List; and in monitoring the HFE design phase of programs. It will be of use to the contractor HFE specialist in preparing proposals and in performing the HFE design phase of contracts.

The guide complementary to this one for managers of the human engineering design phase of a program (Reference 5) contains less detail about HFE design techniques than this user's guide.

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5. English, M., Navy Manager's Guide for the Design Sections of MIL-H-46855, NADC-79219-60, BAC, NADC, 26 September 1980.

2.0 Documented Requirements for HFE Design

General requirements for Navy system acquisition, including the design phase of system acquisition, are in Department of Defense (DoD) directives and in Secretary of the Navy (SECNAV) and Chief of Navy Material (NAVMAT) instructions. General HFE design requirements are in NAVMAT instructions. Specific HFE design requirements and criteria are in military specifications and standards. Specific HFE design products which a system contractor must deliver to the Navy are in Data Item Descriptions. HFE design principles and design data are in HFE guides, handbooks and general literature. HFE design techniques are in this guide.

2.1 DoD and Navy Design Directives and Instructions

In 1971, the Deputy Secretary of Defense established the policy for major defense systems acquisition by the military services in DoD Directive 5000.2 (Reference 7). The Secretary of the Navy implemented this policy in SECNAVINST 5000.1 (Reference 8). The Chief of Navy Material established the general requirement for performing HFE design during systems acquisition in NAVMATINST 3900.9 (Reference 9). This instruction states that the human element of a Navy system shall undergo the same development, test, and evaluation steps as equipment elements of the same system.

2.2 Military Specifications and Standards

In 1966, specific requirements for HFE design during systems acquisition were established in military specification MIL-H-46855

7. DoD Directive 5000.2, "Major System Acquisition Process", Washington, D.C., 1971.
8. SECNAVINST 5000.1, "System Acquisition in the Department of the Navy", 1972.
9. NAVMATINST 3900.9, "Human Factors", Department of the Navy, Headquarters Naval Material Command, Washington, D. C., September 1970.

(Reference 1). Also in 1968, specific HFE design criteria were established in military standard MIL-STD-1472 (Reference 10). Both of these documents have been updated since SECNAVINST 5000.1 (Reference 8) was published. These two documents are usually cited in a contract between the Navy and industry as containing the contractual HFE design requirements and criteria.

There are other military standards which contain specialized HFE design criteria and which may be cited in a contract. Examples of these standards are: MIL-L-25467 (Instrument Lighting), MIL-STD-411 (Air Crew Station Signals), and MIL-STD-1333 (Air Crew Station Geometry). There are also other military specifications which affect HFE design and which may be cited in the contract. An example of one of these specifications is MIL-M-8650 (General Specification for Aircraft Mockups).

The contents of MIL-H-46855 (Reference 1) and MIL-STD-1472 (Reference 10), which are usually the Navy's and the contractor's primary sources of HFE design requirements and design criteria, are discussed below.

MIL-H-46855

MIL-H-46855 has separate sections containing requirements for HFE analysis, design, and test and evaluation. The relationship of the sections is illustrated in Figure 2.0-1. The contents of the design requirements sections (3.2.2 and its subparagraphs) are described below. A copy of the complete text of Section 3.2.2 is in Appendix B.

Section 3.2.2 "Human Engineering in Equipment Detail Design" is divided into four subsections: studies, experiments and laboratory tests;

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1. MIL-H-46855A, Human Engineering Requirements for Military Systems, Equipment and Facilities, 4 May 1972.
8. SECNAVINST 5000.1, "System Acquisition in the Department of the Navy", 1972.
10. MIL-STD-1472B, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, 31 December 1974.

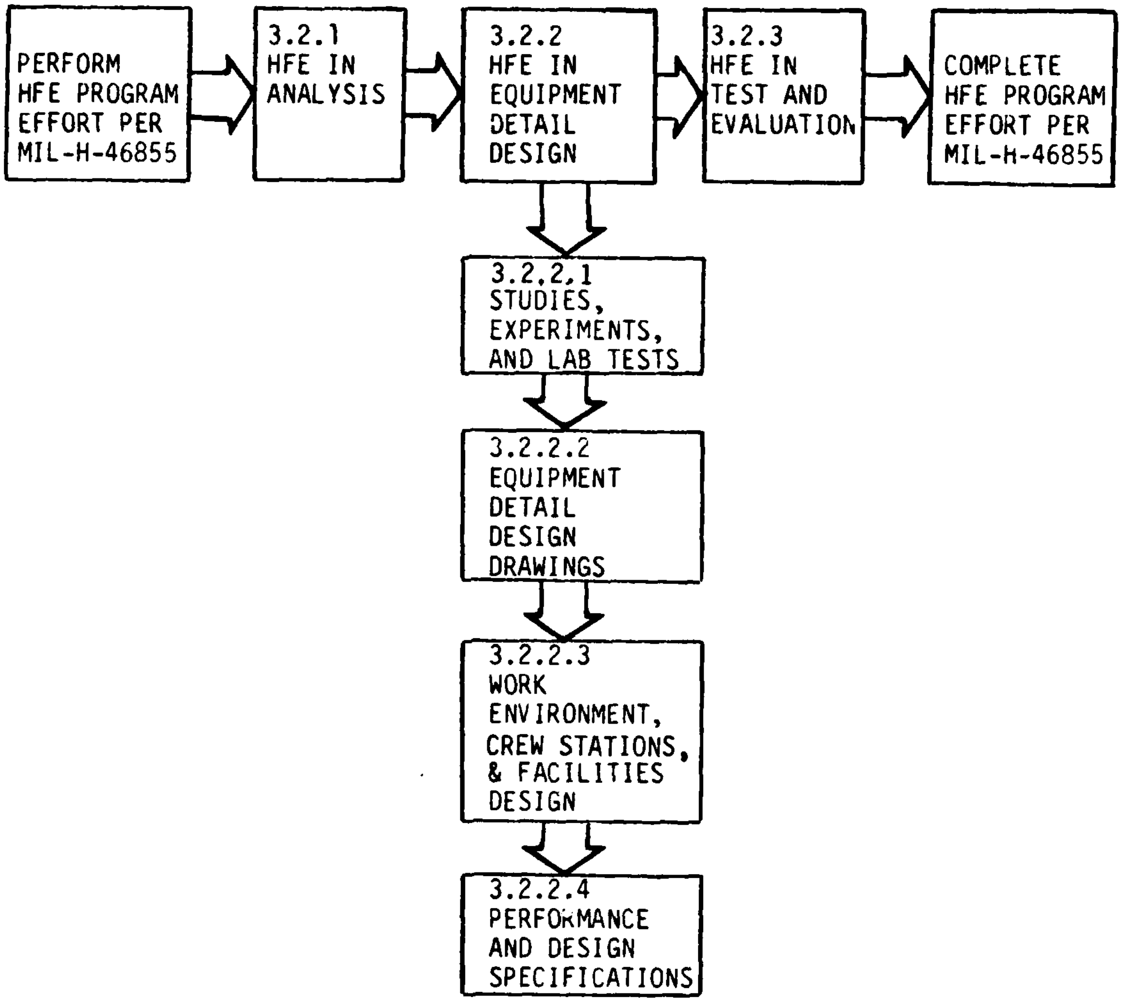

FIGURE 2.0-1 - MIL-H-46855 RELATIONSHIPS

equipment detail design drawings; work environment, crew stations and facilities design; and performance and design specifications.

Paragraph 3.2.2.1 (studies, experiments and laboratory tests) states that human engineering and life support problem areas must be identified, called to the attention of the procuring activity, and resolved in a timely manner, by studies, experiments and laboratory tests if necessary, so that the results can be incorporated into equipment design.

Paragraph 3.2.2.2 (equipment detail design drawings) states that equipment drawings must be evaluated to assure that human engineering principles and criteria have been applied to the design of the equipment represented by the drawings and that they comply with MIL-STD-1472.

Paragraph 3.2.2.3 (work environment, crew stations and facilities design) states that human engineering principles and criteria must be applied to detail design of work environments, crew stations, and facilities to be used by the human in the system and that the design of these items must comply with MIL-STD-1472. The effect on human performance under normal, unusual and emergency conditions must be considered.

Paragraph 3.2.2.4 (performance and design specifications) states that performance and design specifications for the system must comply with MIL-STD-1472 and other human engineering criteria cited in the contract.

MIL-STD-1472

As noted in the description of MIL-H-46855 above, military standard MIL-STD-1472 (Reference 10) is frequently cited as the primary source of HFE design criteria. Figure 2.0-2 illustrates a page of text from MIL-STD-1472 and Figure 2.0-3 illustrates a suppporting figure referred to in the page of text. This standard contains specific descriptions of the

10. MIL-STD-1472B, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, 31 December 1974.

MIL-STD-1472B
31 December 1974

5.2.1.3 Location and Arrangement -

5.2.1.3.1 Accuracy - Displays shall be located and designed so that they may be read to the degree of accuracy required by personnel in the normal operating or servicing positions.

5.2.1.3.2 Access - Ladders, supplementary lighting, or other special equipment should not be required in order to gain access to or to read a display.

5.2.1.3.3 Orientation - Display faces shall be perpendicular to the operator's normal line of sight whenever feasible and shall not be less than 45^{o} from the normal line of sight (see Figure 1). Parallax shall be minimized.

5.2.1.3.4 Reflection - Displays shall be constructed, arranged, and mounted to prevent reduction of information transfer due to the reflection of the ambient illumination from the display cover. Reflection of instruments and consoles in windshields and other enclosures shall be avoided. If necessary, techniques (such as shields and filters) shall be employed to insure that system performance will not be degraded.

5.2.1.3.5 Vibration

5.2.1.2.5 Vibration - Vibration of visual displays shall not degrade user performance below the level required for mission accomplishment (see para 5.8.4.2).

5.2.1.3.6 Grouping - All displays necessary to support an operator activity or sequence of activities, shall be grouped together.

5.2.1.3.7 Function and Sequence - Displays shall be arranged in relation to one another according to their sequence of use or the functional relations of the components they represent. They shall be arranged in sequence within functional groups whenever possible to provide a viewing flow from left to right or top to bottom.

5.2.1.3.8 Frequency of Use - Displays used most frequently should be grouped together and placed in the optimum visual zone (see Figure 2).

5.2.1.3.9 Importance - Very important or critical displays shall be placed in a privileged position in the optimum projected visual zone or otherwise highlighted.

5.2.1.3.10 Consistency - The arrangement of displays shall be consistent in principle from application to application, within the limits specified herein.

FIGURE 2.0-2 - PAGE OF TEXT FROM MIL-STD-1472

Figure 2. VERTICAL AND HORIZONTAL VISUAL FIELD

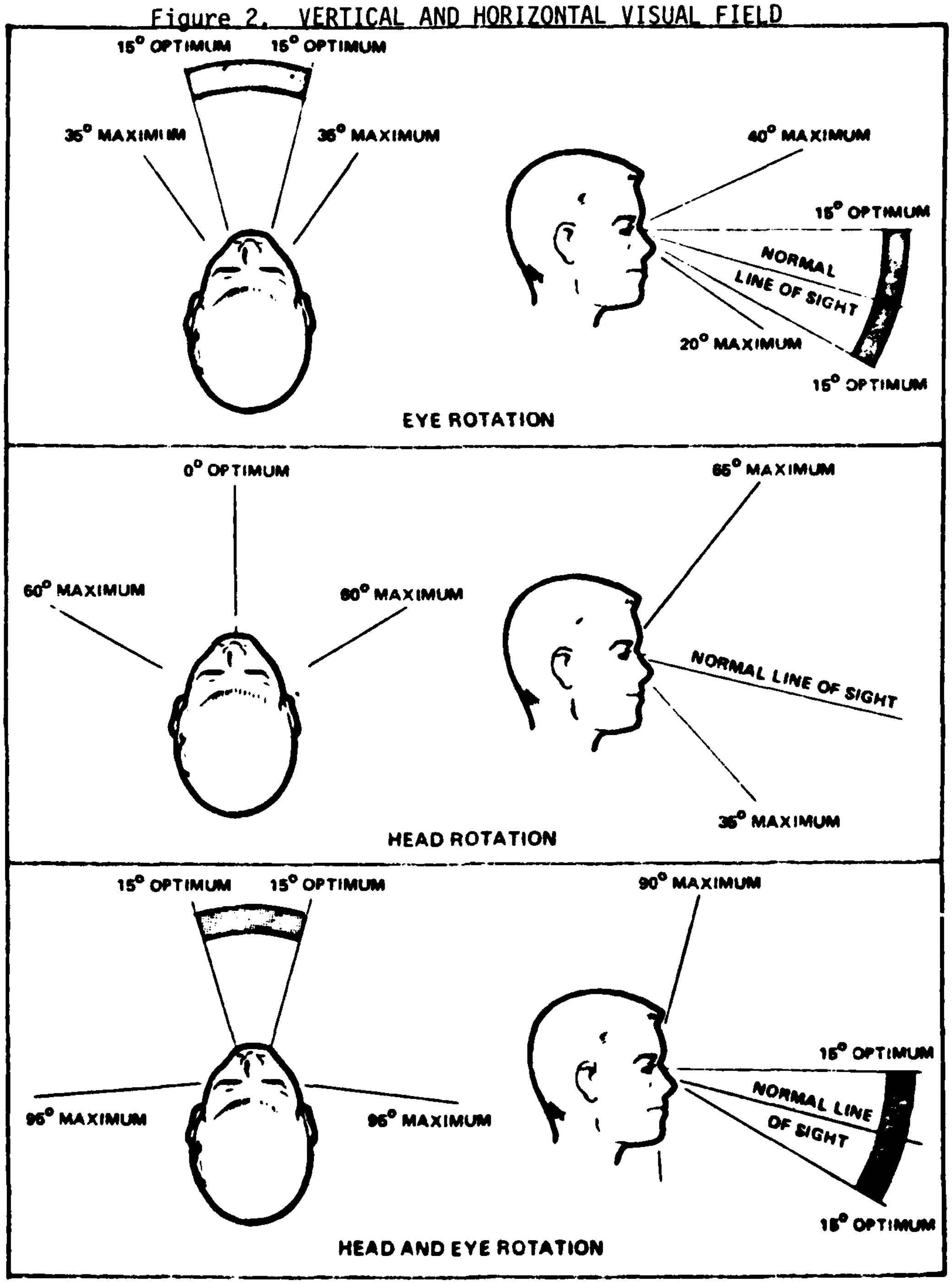

FIGURE 2.0-3 - FIGURE FROM MIL-STD-1472

characteristics which systems, equipment and facilities should have. The purpose of the standard is to specify in terms which are verifiable how equipment and facilities should be designed so as to insure that required operator performance is achieved and that personnel safety is not jeopardized. This standard is so important to HFE design that a checklist based on its contents is a basic HFE design technique (described in Section 7 of this guide).

2.3 Data Item Descriptions

A Navy contract always contains a list specifying exactly what products the contractor must deliver. This list is called the Contract Data Requirements List (CDRL, DD Form 1423). Standardized descriptions of the many products which might be contracted for have been developed. These standardized descriptions are called Data Item Descriptions (DIDs, DD Form 1664). For a specific contract, the appropriate DIDs are selected and included in the CDRL by the Navy.

In 1979, the following updated series of human engineering DIDs were published with ARMY/MIRADCOM as the office of primary responsibility:

DoD DI-H-7051, "Human Engineering Program Plan"
DoD DI-H-7052, "Human Engineering Dynamic Simulation Plan"
DoD DI-H-7053, "Human Engineering Test Plan"
DoD DI-H-7054, "Human Engineering System Analysis Report"
DoD DI-H-7055, "Critical Task Analysis Report"
DoD DI-H-7056, "Human Engineering Design Approach Document-Operator"
DoD DI-H-7057, "Human Engineering Design Approach Document-Maintainer"
DoD DI-H-7058, "Human Engineering Test Report"
DoD DI-H-7059, "Human Engineering Progress Reports"

These DIDs specify in detail the human engineering activities which must be performed by a contractor during systems acquisition and the human engineering products which the contractor must deliver to the Navy. Three of these HE DIDs apply directly to the HFE design process and all of the others apply indirectly.

The text of the three DIDs which apply directly to the design process is in Appendix C and the contents are described below.

DI-H-7052

DI-H-7052, the HE Dynamic Simulation Plan DID, describes in detail how the contractor's dynamic simulation plan should be prepared, if dynamic simulation is going to take place.

DI-H-7056 and DI-H-7057

DI-H-7056 and DI-H-7057, the HE design approach documents for the operator and the maintainer of the system being acquired, explain what the two design approach documents should contain. The operator design approach document must describe the layout, detail design, and arrangement of crew station equipment having an operator interface and the operator tasks associated with the equipment. The document must also describe the extent to which the human performance requirements, MIL-STD-1472 design criteria, and the requirements of other applicable HE documents specified in the contract have been incorporated in the crew station equipment. Results of operator task analysis must be presented as part of the rationale suporting the layout, design, and integration of crew station equipment.

The operator design approach document must contain the following crew station and operator-related information: a list of each item of equipment having an operator interface, a list of specifications and drawings approved by human engineering, and a description of the crew station emphasizing human engineering design features. Design features to be described are: each crew station and each item of crew station equipment; each control/display panel; operator vision to crew station items of equipment and operator external vision; environmental factors; normal and emergency ingress and egress; crew station lighting characteristics and lighting control system; crew station warning, caution and advisory signals; seating. restraint systems and other postural controls; communications systems and communications systems control; any special design, layout, or arrangement features required by mission or system environment; and multiple operator stations design, if applicable. Other information required includes geometric layout of the crew stations; rationale for human engineering design, layout and arrangement of each item of crew station having an operator interface; and narrative which provides rationale for any need to deviate from MIL-STD-1472. Similar information requirements are made for the maintainer design approach document.

All of the other human engineering DIDs indirectly affect the HFE design effort. These DIDs are briefly described below.

DI-H-7051 and DE-H-7059

DI-H-7051 and DI-H-7059, the HE program plan and progress report DIDs, describe how to prepare the program plan and progress reports which, among other things, describe in detail how all HE design requirements are being fulfilled. The HFE specialist may prepare the HE design portion of the plan and reports; if not, these documents will be a source of information to the specialist.

DI-H-7053 and DI-H-7058

DI-H-7053 and DI-H-7058, the HE test plan and test report DIDs, describe how to prepare the documentation associated with contractor tests. It is part of the test evaluation function rather than the design function to perform these tests and document them, but the test results are used by the Navy to assure that the human-equipment interface which is designed during the design phase conforms to the contractual requirements.

DI-H-7054 and DI-H-7055

DI-H-7054 and DI-H-7055, the HE system analysis and critical task analysis report DIDs, describe the system analysis and critical task analysis that must be done. These reports are sources of input data from the analysis phase to the design phase.

2.4 Guides, Handbooks, and General Literature

There are a number of guides and handbooks and a quantity of general literature which contain information about HFE design. HFE design guides and handbooks were a source of information for MIL-STD-1472, and searches of the general literature are a standard human engineering design technique. Some of these publications are referenced in the guides for analysis and test and evaluation (References 2 and 3).

3.0 Practical Requirements for HFE Design

The practical requirements for HFE design underly the documented requirements and are what caused the documented requirements to come into being. These practical requirements include the need for operators and maintainers to be able to consistently perform with a certain level of accuracy and speed in order to have systems achieve their desired capabilities, the need to protect the operators and maintainers from injury or death, the need for special equipment to keep operators and maintainers alive in systems operating in environments hostile to human life, and the need to minimize requirements for large numbers of highly skilled and trained personnel. Each of the practical requirements is briefly discussed below.

3.1 Human Performance

Each system requires a certain level of human performance in order to function as specified. In order to meet system performance requirements such as speed, maneuverability, range, or turnaround time, the operators and maintainers of the system must meet certain minimum requirements for

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2. Geer, C. W., Analyst's Guide for the Analysis Sections of MIL-H-46855, D1880-19476-1, Boeing Aerospace Company (BAC), Naval Air Development Center (NADC), Warminster, Pa., 30 June 1976.
3. Geer, C. W., User's Guide for the Test and Evaluation Sections of MIL-H-46855, D194-10006-1, BAC, NADC, 30 June 1977.

performing their assigned tasks. Human performance requirements for a system are usually expressed in terms of time to perform a task, accuracy of performance, and consistency (reliability) with which the speed and accuracy can be maintained. Some of the documented HFE design criteria exist to assure the achievement of necessary operator and maintainer task times and error rates.

3.2 Safety

In order to achieve the required level of system performance and for humane reasons, operator and maintainer personnel must be protected from injury and death. Some of the documented HFE design criteria exist to assure the safety of system personnel.

3.3 Life Support Criteria

In high performance systems and systems requiring closed loop environmental control, life support requirements are particularly critical. Some of the documented HFE design criteria exist to assure the adequacy of life support features of systems.

3.4 Personnel Quantities/Skills/Training

The number of personnel required to operate and maintain a system and the level of skill and amount of training these personnel must have greatly impacts the cost of a system and the lead time required to get the system into operation. Some of the documented HFE design criteria exist to avoid the need for extra personnel, skills and training in order to operate or maintain poorly designed equipment.

4.0 Basic Considerations in HFE Design

There are several basic considerations which must be taken into account in planning and accomplishing an HFE design effort. These considerations include the type of data required to begin an HFE design effort, the timing of the HFE design effort, and products which will be produced by the HFE design effort.

4.1 Data Inputs to The Design Process

The data inputs to the design process consist of the outputs of the analysis phase plus data that is generated during the design phase. The analyst's guide (Reference 2) describes a number of analysis techniques. Ideally, enough analysis will have been done during the analysis phase to provide the required design input data. If not, some analysis will have to be performed at the beginning of the design phase. A sampling of the analysis activities which precede design activities are described below.

1) Mission analysis is performed and mission profiles are produced which give the HFE specialist a good idea of the operational situation or events that will be confronting operators and maintenance personnel.

2) Mission scenarios which fully describe the events implied by the mission profiles are written in narrative form describing the proposed mission in detail and identifying key events and implied requirements. All essential system functions such as failure modes or emergency procedures are included. The mission scenarios are sufficiently detailed to give the HFE specialist an understanding of the mission.

3) Functional flows are developed for detailed system requirements down to the level of specific operator tasks. Significant operator performance requirements and the details of critical operator tasks are determined. Early estimates are made of likely crew interface requirements, capability, special provisions needed, potential problems and probable solutions.

4) Preliminary workload data are estimated and information provided for manning and training estimates.

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2. Geer, C. W., Analyst's Guide for the Analysis Sections of MIL-H-46855, D1880-19476-1, Boeing Aerospace Company, Naval Air Development Center, Warminster, Pa., 30 June 1976.

5) Decision/action diagrams are prepared showing the flow of required system data in terms of operations and decisions. These diagrams record the sequence of operations and decisions which must be performed.

6) Action/information requirements analysis defines the specific actions necessary to perform a function and the specific information that must be provided to perform the action. The HFE specialist performing the analysis pairs action requirements with possible control hardware and information requirements with possible display hardware.

7) Function allocation trades are made to provide the baseline for crew task definition, control and display operations requirements, crew station configuration concepts, workload evaluation and crew station design and evaluation. The allocation of functions, actions, and decisions is based on the known capabilites and limitations of operators, the state of the art of hardware and software, and estimated performance to be required in terms of speed, accuracy and load.

8) Timelines are prepared to examine time and errors. Time-critical sequences are analyzed to verify that all necessary events can be performed. The occurrence of incompatible tasks is assessed and workload is evaluated from the timelines.

9) Flow process charts are prepared showing the flow of operator activities and information exchange in time sequence. These flow process charts are used to develop and evaluate concepts for each operator station.

10) Operational sequence diagrams are prepared providing a graphic presentation of operator tasks as they relate sequentially to both equipment and other operators. Symbols are used to indicate

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2. Geer, C. W., Analyst's Guide for the Analysis Sections of MIL-H-46855, D-1880-19476-1, Boeing Aerospace Company, Naval Air Development Center, Warminster, Pa., 30 June 1976.

actions, inspections, data transmitted or received, data storage, and decisions to show the flow of information through a system.

4.2 Timing of the Design Effort

In order to have maximum impact on design, the HFE design effort must occur at the proper time in the overall design effort. The timing of the HFE design effort as it relates to other HFE activities and to overall program phases is illustrated in Figure 4.0-1. The timing of some of the details of the HFE design effort is discussed below.

Ordinarily, 30 days after contract award a Technical Interchange meeting between Navy and contractor HFE specialists occurs. At this meeting, arrangements can be made for weekly telephone contact or other means of keeping in close touch. Scheduled contacts include Preliminary Design Reviews, Critical Design Reviews, and Lighting Mockup Reviews.

At the beginning of the design phase, contractor HFE specialists will immediately prepare HFE design criteria in a format appropriate for early transmittal to systems designers. Contractor HFE specialists will maintain close contact with designers, as it is always easier to get input accepted while the designer is sketching at the drafting board than after a design concept is finalized in drawing form. Contractor HFE specialists will also prepare their own conceptual design sketches of control and display consoles and other critical human-equipment interfaces as early as possible in order to have maximum impact on system design. All design techniques described in Sections 7 and 8 will be performed as early in the design process as the data can be obtained or generated.

4.3 Products of the HFE Design Effort

The products of the HFE design effort are designs of human-machine interfaces, evaluation of these designs, and documentation that HFE design

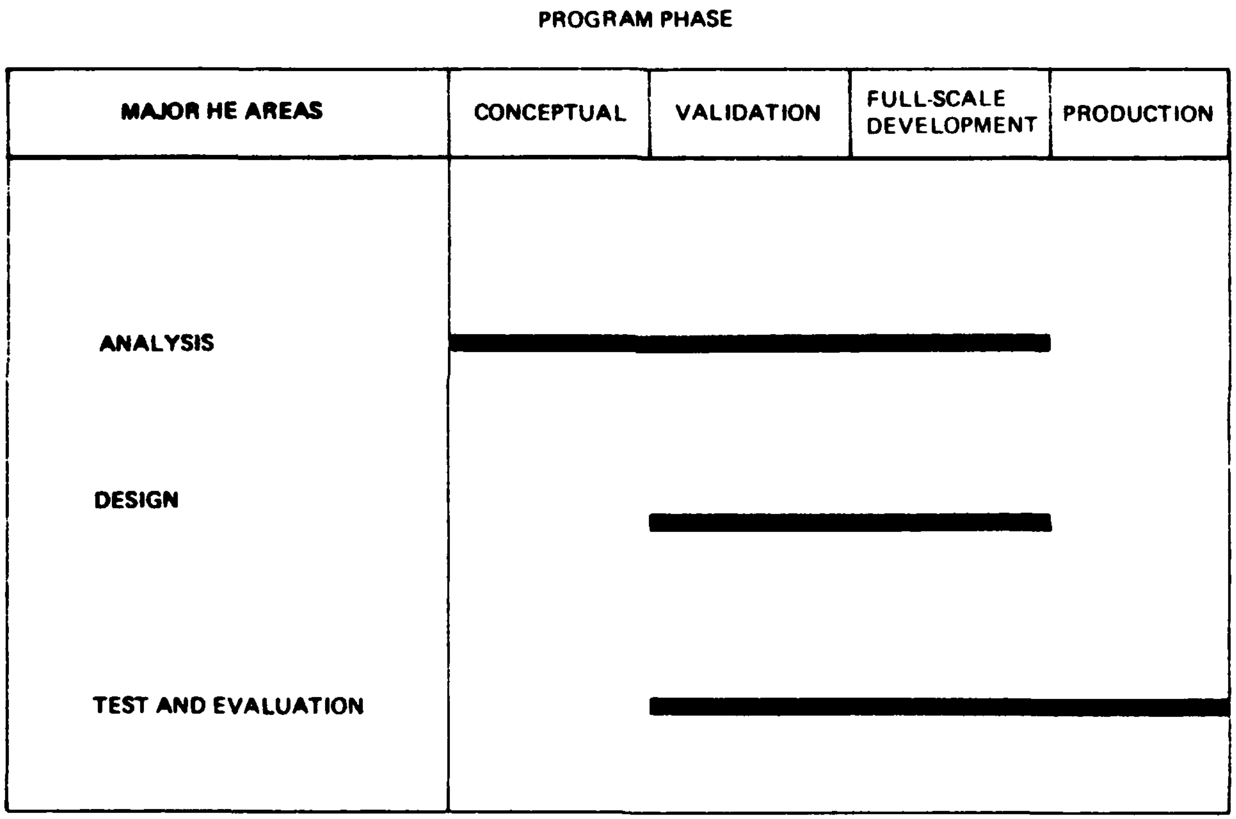

FIGURE 4.0-1 - TIMING OF THE HFE DESIGN EFFORT

criteria have or have not been met. Records of designs, design recommendations, and design evaluations and their rationale are kept on file in the contractor's HFE office.

5.0 The HFE Design Process

The purpose of the design phase of a program is to convert the concepts arrived at in the analysis phase (Reference 2) into a system design represented by engineering drawings and to build the first hardware. The purpose of performing HFE during the design phase is to produce a system design which correctly utilizes human capabilities and does not exceed human limitations. This goal is accomplished by incorporating the HFE design criteria in MIL-STD-1472 and other relevant HFE design criteria into all parts of the system which have human-machine interfaces.

HFE design criteria describe the characteristics which human-machine interfaces should have and are based on HFE knowledge of human capabilities and limitations derived from laboratory research and years of field experience. Incorporation of HFE design criteria into system design will assure that the system can be efficiently operated by its human operators and that the design of the system does not lead these operators to commit errors. Human-machine interfaces include hardware, software, procedures, work environment, and facilities.

5.1 Role of the HFE Specialist

During system design, the HFE specialist may perform one or more of the following roles: contract monitor, equipment designer, consultant to equipment designers, and evaluator of equipment designs. Which of these roles is performed depends partly on whether the specialist represents the

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2. Geer, C. W., Analyst's Guide for the Analysis Sections of MIL-H-46855, D1880-19476-1, Boeing Aerospace Company, Naval Air Development Center (NADC), Warminster, Pa., 30 June 1976.

Navy or the contractor and partly on the type of program and the structure of the specialist's organization. The roles usually performed by Navy and contractor HFE specialists are indicated below:

	HFE Specialist	
	Contractor	Navy
1) contract monitor		X
2) equipment designer	X	
3) consultant to equipment designers	X	
4) evaluator of equipment designs	X	X

Contract Monitor

When performing as contract monitor, the Navy HFE specialist monitors all of the activities and products of the contractor HFE specialist through Technical Interchange Meetings, Preliminary Design Reviews, Lighting Mockup Reviews, Critical Design Reviews, telephone conversations, and review of documentation prepared. The contract monitor also monitors any operator-machine interface designs produced by a contractor which have not had contractor HFE input. On occasion, the contractor HFE specialist may be contract monitor of subcontractor HFE efforts.

Designer

When performing as designer, the HFE specialist (usually the contractor HFE specialist) lays out controls and displays and other critical human-machine interfaces in sketch format. Sometimes the sketches are converted into finished drawings in the HFE group but more often they are given to the design engineers very early in the design phase in order to get the concepts incorporated into the design engineers' final designs.

Design Consultant

When performing as design consultant, the HFE specialist (usually the contractor HFE specialist) provides HFE design criteria and other guidance to design engineers. The design criteria may be prepared in the form of an annotated MIL-STD-1472 checklist as described in Section 7, a list of available parts which meet MIL-STD-1472 requirements, a design layout sketch as described in the preceding paragraph, listing and clarification of the requirements of other military standards and specifications, guidelines representing HFE principles not incorporated in military standards and specifications, and verbal information provided spontaneously or in response to questions from designers. In the consultant role, it is important for the HFE specialist to have constant interaction with system designers and to establish a good working relationship so that HFE input will be incorporated.

Design Evaluator

Design evaluator is one of the HFE specialist's most frequently performed roles. The designs produced by the contractor's design engineers are evaluated first by the contractor HFE specialist and later by the Navy HFE specialist. As design evaluator, the HFE specialist uses the MIL-STD-1472 checklist, simulated task performance in mockups, and other techniques described in Sections 7 and 8. The contractor specialist documents compliance with MIL-STD-1472 design criteria and any other HFE contractual design criteria and prepares requests for deviation where appropriate. The Navy specialist reviews the contractor's documentation, personally applies the MIL-STD-1472 checklist and other HFE criteria to selected hardware, and approves or disapproves the requests for deviation.

5.2 General Purposes of Design Techniques

In performing the roles described in the preceding section, the HFE specialist must specify the contents of HFE design criteria, incorporate these design criteria into designs, determine whether the designs meet the design criteria, and document that the design criteria have been met.

The specialist uses various techniques to accomplish these activities. To specify the contents of HFE design criteria, the specialist uses contractural documents and military specifications and standards. To incorporate design criteria into designs and to determine whether design criteria have been met, the specialist uses design criteria checklists, measurment equipment, and the other techniques mentioned in paragraph 5.3 below. To document that design criteria have been met, the specialist using drawing signoffs, design reviews, and deviation requests. Some of these techniques are described in detail in Section 7.

5.3 General Types of Design Techniques

To accomplish the goals referred to in paragraph 5.2 above, the HFE specialist uses techniques to represent the hardware/software, techniques to represent the operator, techniques to represent the operator interacting with the hardware/software, and techniques to solve problems. Techniques representing the hardware/software include sketches, drawings, schematics, mockups, and scale models. A technique representing the operator is anthropometric manikins. Techniques representing the operator interacting with the hardware/software include visibility diagrams, reach envelopes, walkthroughs, simulators, and computer models. Techniques for solving problems include tradeoffs, literature surveys, consultation with other experts, studies and experiments, and individual expert judgment. Many of these techniques are described in detail in Sections 7 and 8.

6.0 Selection of Design Techniques

The choice of a design technique for performing an HFE design activity depends on the activity, on the characteristics of the technique, and on the personnel, time, and equipment available to use the technique. To aid in selecting design techniques, information is provided about the characteristics of each technique and about the relative resource requirements.

The information about the characteristics of each technique contained in Sections 7 and 8 includes a summary description of the technique, a statement of when in the program the technique is used, a description of the product produced by the technique and the purpose of the product, a description of what the HFE specialist must do to use the technique, a list of the technique's advantages and disadvantages, and, for the techniques using computers, an application example if available and the contact for source documents.

Because of the number of variables in a program, it is difficult to provide any actual resource figures for the various techniques. However, to give some idea of resource requirements, the techniques have been compared to each other on the basis of whether the time to perform is short, medium, or long and whether the complexity, cost, and cost effectiveness is low, medium, or high. This comparison appears in Table 6.0-1.

COMPARISON OF DESIGN TECHNIQUES												
DESIGN TECHNIQUES	Relative complexity			Relative time to perform			Relative cost			Relative cost effectiveness		
	Simple	Average	Complex	Short	Medium	Long	Low	Medium	High	Low	Medium	High
STANDARD TECHNIQUES (SECTION 7)												
CONTRACTUAL DOCUMENTS	X	X			X	X		X			X	
DESIGN CRITERIA CHECKLISTS	X	X		X	X			X				X
ENGINEERING DRAWINGS		X			X			X			X	
MOCKUPS		X			X	X		X	X		X	X
SCALE MODELS		X			X		X	X		X	X	
MANIKINS		X			X		X				X	X
VISIBILITY DIAGRAMS		X			X			X			X	
REACH ENVELOPES		X			X			X			X	
COMPUTER TECHNIQUES (SECTION 8)*												
CAD			X			X			X		X	
CAPE			X		X	X		X	X		X	
CAR			X		X	X		X	X		X	X
CGE			X			X			X		X	
COMBIMAN			X			X			X		X	
CUBITS		X	X		X			X	X		X	
HECAD			X			X			X		X	
HOS			X			X		X	X		X	X

*COMPUTER TECHNIQUE ACRONYMS ARE DEFINED IN SECTION 8.

TABLE 6.0-1 - RESOURCE COMPARISON OF DESIGN TECHNIQUES

7.0 Standard Design Techniques

The techniques described in this section have been used by HFE specialists for a number of years. These techniques have been found to have a great deal of utility, and in fact, human engineering design could not be accomplished without some of them.

7.1 Design Techniques For Design Criteria Specification, Incorporation, Evaluation, or Documentation

The design techniques described in this section are used to specify HFE design criteria, to incorporate HFE design criteria into designs, to evaluate whether HFE design criteria have been incorporated into designs, and to document compliance with HFE design criteria.

7.1.1 Contractual Documents

The System Specifications and the Statement of Work (SOW) are contractual documents. It is important to have human engineering design requirements and criteria written into these documents to give visibility and authority to HFE during system design. The Navy HFE specialist is primarily responsible for accomplishing this objective. The process is described below.

7.1.1.1 System Specifications. The system specifications document is the basic source of design requirements for the system being acquired.

Summary Description: The system specification document contains individual specifications for each major hardware item making up the system. Each specification states the criteria which the item it refers to must meet. Each individual item specification contains a human engineering (HE) specification. The HE specification states the HE criteria which the item must meet. The system specifications also have a section for stating how the fact that the criteria have been met will be verified.

How Prepared/Used: The Request for Proposal (RFP) for a new or updated system contains system specifications prepared by the Navy. The

Navy HFE specialiist should write the human engineering specification included in the systems specifications.

There are several documents describing how to prepare system specifications and stating what the human engineering specifications must be. These documents are described below.

1) MIL-STD-490, Specification Practices. MIL-STD-490 (Reference 11) contains instructions for writing system specifications. According to Section 4.3.3.7 of MIL-STD-490, a system specification document must contain a section listing the human engineering requirements which the system must meet. Section 4.3.3.7 is quoted below.

> Human Engineering Section (4.3.3.7) of MIL-STD-490:
>
> "Human engineering requirements for the system/item should be specified herein and applicable documents (e.g., MIL-STD-1472) included by reference. This paragraph should also specify any special or unique requirements, e.g. constraints on allocation of functions to personnel, and communications and personnel/equipment interactions. Included should be those specified areas, stations, or equipment that require concentrated human engineering attention due to the sensitivity of the operation or criticality of the task, i.e., those areas where the effects of human error would be particularly serious."

A typical human engineering specification is quoted below:

> Human Engineering Section (3.3.7) of Typical System Specification:
>
> "Human engineering principles and procedures shall apply throughout the design, development, manufacture, test and installation of all equipment and human/machine interfaces provided to satisfy the requirements of this document. Human engineering goals shall be to maximize use/effectiveness of human resources and in so doing shall minimize staffing, operator error, task complexity, and task time. The human engineering requirements and criteria of MIL-H-46855 and MIL-STD-1472 shall apply."

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11. MIL-STD-490, Specification Practices, 30 October 1968.

Section 4.3.3.7 of the system specifications must contain information as to how verification that the criteria have been met will be performed. A typical system specifications Section 4.3.3.7 is quoted below:

Performance Verification Section (4.3.3.7) of Typical System Specification

> "Human Performance/Human Engineering requirements shall be verified through analysis, inspection, demonstration and test in accordance with criteria of MIL-H-46855."

2) MIL-H-46855, Human Engineering Requirements for Military Systems, Equipment and Facilities. MIL-H-46855 is the military specification which contains the human engineering requirements for military systems. It requires the performance of human engineering (HE) analysis, HE design criteria development, and HE test and evaluation. The specification is periodically updated as the philosophy of the HFE community evolves. Section 3.2.2.4 referring to system specifications is quoted below:

MIL-H-46855, Section 3.2.2.4:

> "The provisions of performance and design specifications, prepared by the contractor, shall conform to applicable human engineering criteria of MIL-STD-1472 and other human engineering criteria specified by the contract."

3) MIL-STD-1472, Human Engineering Design Criteria for Military Systems, Equipment and Facilities. MIL-STD-1472 is the military standard which contains the detailed human engineering design criteria which equipment and other operator-interface items in the system must meet. It describes criteria that should be applied in order to achieve required operator performance. These criteria are based on practical experience and laboratory research with design features that minimize errors and speed performance. The standard contains comment forms to be filled out by members of the HFE community who use it and is periodically updated in response to these comments and to incorporate new data which becomes available.

4) Other Contractual Human Engineering Criteria. Similar systems may exist or previous research may have been done which is relevant to this system. If so, HFE design criteria from these sources may be included in the Request for Proposal and Statement of Work.

When Used: The Navy HFE specialist should become familiar with the instructions for writing system specifications. During Request for Proposal preparation, the Navy HFE specialist should write the HE specification portion of the system specifications. How this participation is accomplished depends on the structure of the specialist's organization.

Advantages: Writing HFE design criteria into the system specifications increases the probability that HFE will be performed during system design. Research has shown that when material on operator considerations is included in the procurement specification, design engineers give these considerations more weight in their decisions than they otherwise would (Reference 12).

Limitations: 1) Design specifications are not self-enforcing. The Navy HFE specialist must continue to monitor the system throughout its development to assure compliance with specifications.

2) The design features which will make an item of hardware comply with a standard are not always obvious from the standard. Any one of several different designs may comply with some standards. In these cases, the professional judgment of the HFE specialist is especially important in determining whether the hardware meets the standards.

7.1.1.2 Statement of Work.

Summary Description: The Statement of Work (SOW) is a document describing in detail the work which will be performed by the contractor.

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12. Meister, D., Human Factors: Theory and Practice. Wiley, New York, 1971.

How Prepared/Used: The SOW is the contractual vehicle by which the Navy specifies to contractors who are bidding on a system whether all of MIL-H-46855 and MIL-STD-1472 will be applied or whether selected parts will be applied (tailoring). It also specifies what the selected parts will be. The Navy HFE specialist should become familiar with the tailoring guidelines in MIL-HDBK-248(AS) (Reference 13). The specialist should make the decision as to whether to tailor MIL-H-46855 and MIL-STD-1472 and if tailoring is to be done should select the relevant parts of the documents. The subject of tailoring is discussed in both the Advantages and the Limitations paragraphs below.

When Used: The proposed SOW is prepared by the Navy as part of a Request for Proposal (RFP). A contractor's proposal, which may include a reworded SOW, is prepared in response to the RFP. When the contract is awarded, the final SOW written by the Navy is a part of the contract.

Advantages: Using the SOW as a design tool is extremely important if all of MIL-H-46855 and MIL-STD-1472 are included or if the two documents are appropriately tailored. Specific references to MIL-H-46855 and MIL-STD-1472 in the proposed SOW accompanying the RFP encourages contractors to include the cost of HFE in their proposals and increases the probability of HFE being performed during system design.

Limitations: 1) The SOW like the system specifications is not self-enforcing. The Navy HFE specialist must continue to monitor the system throughout its development to ensure adherence to HFE design criteria.

2) The danger of the Navy tailoring MIL-H-46855 or MIL-STD-1472 in the proposed SOW is the difficulty of doing appropriate tailoring. MIL-H-46855 can be tailored by a knowledgeable person to reduce the cost of a system, especially a less complex system, without compromising the

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13. MIL-HDBK-248(AS), Tailoring Guide for Application of Specifications and Standards in Naval Weapons Systems Acquisitions, 1 April 1977.

quality of human engineering of the system. For example, paragraphs specifying the construction of HFE mockups or HFE simulators or the conduct of HFE tests of human performance can be considered for tailoring. If the necessary HFE data can be collected in conjunction with hardware mockups, hardware simulators, or hardware testing, it may be possible to tailor these requirements out of MIL-H-46855.

While tailoring MIL-H-46855 may be practical, tailoring MIL-STD-1472 by the Navy in the proposed SOW is risky. If items are tailored out which should have been left in, a good deal of the value of requiring that HFE be applied during system design is negated. In effect, some parts of the system will have HFE principles and criteria applied to them and others will not.

It is extremely important that any tailoring of MIL-H-46855 or MIL-STD-1472 in the SOW should be done by an HFE specialist who is very familiar with the contents of the two documents and who understands their implications. The specialist should keep in mind the fact that during the design phase the system may develop in unanticipated ways, such as controls or displays being added. MIL-STD-1472 is largely self-tailoring in that provisions which do not apply cannot be performed by the contractor. For example, a system which has no displays cannot have the Displays section of MIL-STD-1472 applied to it. It is advisable for the Navy not to tailor MIL-STD-1472 at all in the proposed SOW and to leave any tailoring to the contractor.

The responsibility for the accuracy of any tailoring done in the proposed SOW received by the contractor rests almost entirely on the shoulders of the Navy HFE specialist. Even if the contractor HFE specialist should wish to revise inappropriate tailoring in the Navy's SOW, a contractor ordinarily will not include the cost of additional human factors engineering which the customer did not ask for in a bid because the bid would not be competitive. On the other hand, if the entire MIL-STD-1472 is included in the proposed SOW, the contractor may suggest appropriate tailoring of MIL-STD-1472 in a proposal.

7.1.2 Design Criteria Checklist. HFE evaluation checklists have been in use for more than 25 years. The use of checklists is described in the general literature as early as 1956 (Reference 14). A MIL-STD-1472 checklist was developed for the Minuteman Missile system by the Boeing Company in 1966.

Summary Description: A design criteria checklist is a list of HFE design criteria which must be met by the equipment and facilities in a system. Most of the items on the checklist come from MIL-STD-1472, which can be adapted to checklist form. Some checklist items may be taken from other relevant HFE references. Figure 7.0-1 illustrates a page of text from a MIL-STD-1472 checklist and Figure 7.0-2 illustrates a supporting figure referenced in the page of text.

Since MIL-STD-1472 currently contains over 200 pages, some method of organizing the items was necessary. MIL-STD-1472 is divided into categories such as visual displays, audio displays, controls, and labelling. There are usually four columns to the right of each item to indicate compliance, noncompliance, or not applicable and to make comments.

When Used: Checklist evaluation is performed on each item which has an operator interface as soon as the item exists in a form which can be evaluated, usually when the drawings of the item are completed. Additional checklist evaluations are performed if the item is mocked up or simulated. The checklist is eventually used to evaluate the first production hardware.

Product and Purpose: The checklist is used to evaluate engineering drawings, any mockups or simulators which are built, and the first production hardware. The completed checklist provides documentation that the HFE design criteria have or have not been met.

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14. Van Cott, H. P. and Altman, J. W., Procedures for Including Human Engineering Factors in the Development of Weapon Systems, WADC Technical Report 56-488, AD-97305, American Institute for Research, Wright Air Development Center, October 1956.

MIL-STD-1472B
31 December 1974

5.2.1.3 Location and Arrangement -

5.2.1.3.1 Accuracy - Displays shall be located and designed so that they may be read to the degree of accuracy required by personnel in the normal operating or servicing positions.

5.2.1.3.2 Access - Ladders, supplementary lighting, or other special equipment should not be required in order to gain access to or to read a display.

5.2.1.3.3 Orientation - Display faces shall be perpendicular to the operator's normal line of sight whenever feasible and shall not be less than 45° from the normal line of sight (see Figure 1). Parallax shall be minimized.

5.2.1.3.4 Reflection - Displays shall be constructed, arranged, and mounted to prevent reduction of information transfer due to the reflection of the ambient illumination from the display cover. Reflection of instruments and consoles in windshields and other enclosures shall be avoided. If necessary, techniques (such as shields and filters) shall be employed to insure that system performance will not be degraded.

5.2.1.3.5 Vibration - Vibration of visual displays shall not degrade user performance below the level required for mission accomplishment (see para 5.8.4.2).

5.2.1.3.6 Grouping - All displays necessary to support an operator activity or sequence of activities, shall be grouped together.

5.2.1.3.7 Function and Sequence - Displays shall be arranged in relation to one another according to their sequence of use or the functional relations of the components they represent. They shall be arranged in sequence within functional groups whenever possible to provide a viewing flow from left to right or top to bottom.

5.2.1.3.8 Frequency of Use - Displays used most frequently should be grouped together and placed in the optimum visual zone (see Figure 2).

5.2.1.3.9 Importance - Very important or critical displays shall be placed in a privileged position in the optimum projected visual zone or otherwise highlighted.

5.2.1.3.10 Consistency - The arrangement of displays shall be consistent in principle from application to application, within the limits specified herein.

COMPLIANCE			COMMENTS & DISPOSITION
YES	NO	▷	

FIGURE 7.0-1 - PAGE OF TEXT FROM A MIL-STD-1472 CHECKLIST

Figure 1. LINES OF SIGHT

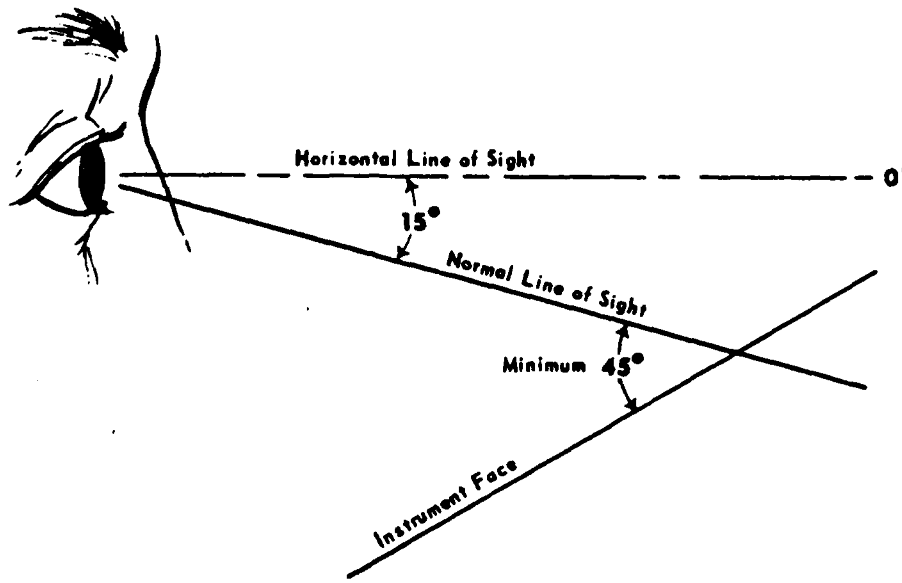

FIGURE 7.0-2 - FIGURE FROM A MIL-STD-1472 CHECKLIST

Procedure for Use: The contractor HFE specialist can easily prepare a MIL-STD-1472 checklist by photocopying pages from MIL-STD-1472 at a convenient percentage of reduction and drawing columns to the right. If other sources of HFE design criteria are specified in the contract, these criteria can be extracted and included in the checklist.

Experienced Navy and contractor HFE specialists will be familiar with the contents of MIL-STD-1472 but the inexperienced specialist will have to become familiar with the contents. The specialists should also become familiar with the purpose or function of each design item to which MIL-STD-1472 is to be applied.

An experienced contractor HFE specialist may perform a drawing evaluation from memory having learned the relevant criteria for specific items from many repetitions. This same specialist has probably determined from experience that some MIL-STD-1472 HFE criteria for an item are more important than others and focuses on the more important criteria in evaluating drawings. The specialist performs the evaluation by reading each criterion, observing the item being evaluated for compliance, and making a checkmark in the appropriate column of the checklist.

Checklist evaluation of drawings is usually done at the specialist's desk using such devices as the anthropometric manikins described in this section plus engineering and architectural measuring scales.

Checklist evaluation of mockups, simulators, or hardware is usually done with no operators present and no equipment working unless a checklist item requires simulated or actual operator action for evaluation. If necessary, a representative of the operator can simulate the actions to be performed by the operator in the mockup, simulator, or hardware. If a checklist item requires actual operation of simulator or hardware, it is more likely to be verified during the test and evaluation phase.

Checklist evaluation of hardware requires measuring equipment such as rules, calipers, force gauges, torque meters, sound level meters, light meters, surface temperature thermometers, and inclinometers.

If a design item does not comply with an HFE criterion, design engineering personnel are informed according to the protocol of the organization. If there is a good reason why an item of hardware does not meet the HFE design criterion and the HFE specialist judges that performance will not be degraded to an unacceptable degree, a request for deviation from the HFE design criterion is prepared, again according to organizational protocol.

Advantages: Although the checklist takes knowledge, time, and effort to use, it is still quicker and easier to use than any other HFE design technique and is the most often used technique for evaluating system design. It is helpful in identifying basic HFE design deficiencies which might otherwise be overlooked until later in system development or not detected until system operation.

Limitations: 1) Since a checklist indicates only whether an item does or does not comply, numerical data will not be recorded even if available.

2) Since criteria in checklists are not prioritized, some other process must be used to separate more important individual noncompliances from the less important ones and to determine the cumulative effect of a number of small noncompliances.

3) Currently, the process of getting approval for a requested MIL-STD-1472 deviation is ill-defined and cumbersome. The contractor HFE specialist prepares the request but the approval routing within both the contractor organization and the Navy organization is ambiguous. A figure of $50,000 per requested deviation has been estimated for processing the paperwork which may contribute to the perception of HFE as a cost driver in system acquisition.

4) Certain criteria in MIL-STD-1472B are almost sure to require deviation requests, for example, the fact that many government specified parts are not built to MIL-STD-1472B criteria.

7.2 Design Techniques to Represent the Hardware/Software

The techniques described below represent the hardware/software.

7.2.1 Drawings

Paragraph 3.2.2.2 of MIL-H-46855 requires that:

> "Human Engineering principles and criteria applied to the design of systems and equipment shall be reflected by the detail design drawings for these systems and equipment to assure that the final product can be efficiently, reliably and safely operated and maintained. The following drawings are included: panel layout drawings, communication system drawings, overall layout drawings, control drawings and other drawings depicting equipment important to system operation and maintenance by human operators. Design shall comply with applicable criteria of MIL-STD-1472 and other human engineering criteria specified by the contract."

Summary Description: Engineering drawings are precise outline drawings which depict the design of an item, facility, or subassembly which is a component or part of the total system. By showing related drawing views, intricate shapes are clearly depicted. Exact sizes are provided without ambiguity. Individual parts are identified for assembly and are located in the assembly in their correct functional position. Descriptive notes provide information as to materials, finishes, and directions for manufacture and assembly. Figure 7.0-3 illustrates an engineering drawing of an aircraft instrument panel.

When Used: Drawings are evaluated by the HFE specialist as soon as they are completed.

Product and Purpose: Drawing evaluation indicates whether the hardware represented by the drawing complies with HFE design criteria. A drawing evaluation using a MIL-STD-1472 checklist provides documentation of whether HFE design criteria have or have not been met.

Procedure for Use: In order to evaluate the engineering drawings developed by project design personnel, the HFE specialist must become knowledgeable of standard procedures for creating engineering drawings to understand the information being presented. Many contractor organizations have training courses in how to read and interpret engineering drawings.

The specialist reviews the drawings to insure the inclusion of appropriate HFE design criteria. The specialist uses a MIL-STD-1472 checklist, any other HFE design criteria checklists that have been prepared for the program, engineering and architectural scales, and the plastic anthropometric manikins described later in this section. When the review has been completed, the HFE specialist should sign off the drawings if they meet the review criteria or should inform the designers of any problems.

Although it is not common, an HFE group may actually prepare engineering drawings. The development of engineering drawings within the HFE group depends on their having the resources to initiate the drawings including the data, the drawing equipment, and the skills of engineers, drafters, and industrial designers. The preparation of workspace layout drawings requires skills in descriptive geometry. The person preparing the drawings must be able to project views and cross sections of the workspace geometry and the human subject into various auxiliary planes which often are not parallel to the normal planes of the three-view or the graphic engineering drawings. Also, for purposes of visual clarity and understanding, perspective drawing techniques should be understood and used. The ability to visualize the geometry of workspace layouts and to prepare drawings depicting the interface relationships is required.

Advantages: Evaluation of design concepts at the drawing stage makes it possible to detect lack of compliance with HFE design criteria before the hardware is built. It is the quickest and easiest design technique.

Limitations: 1) Not all characteristics of three-dimensional crewstations can be evaluated adequately from two-dimensional drawings.

2) If the HFE specialist obtains the engineering drawings through a computer retrieval system using aperture cards, the drawings will be in more different scales than manikins are available to evaluate them.

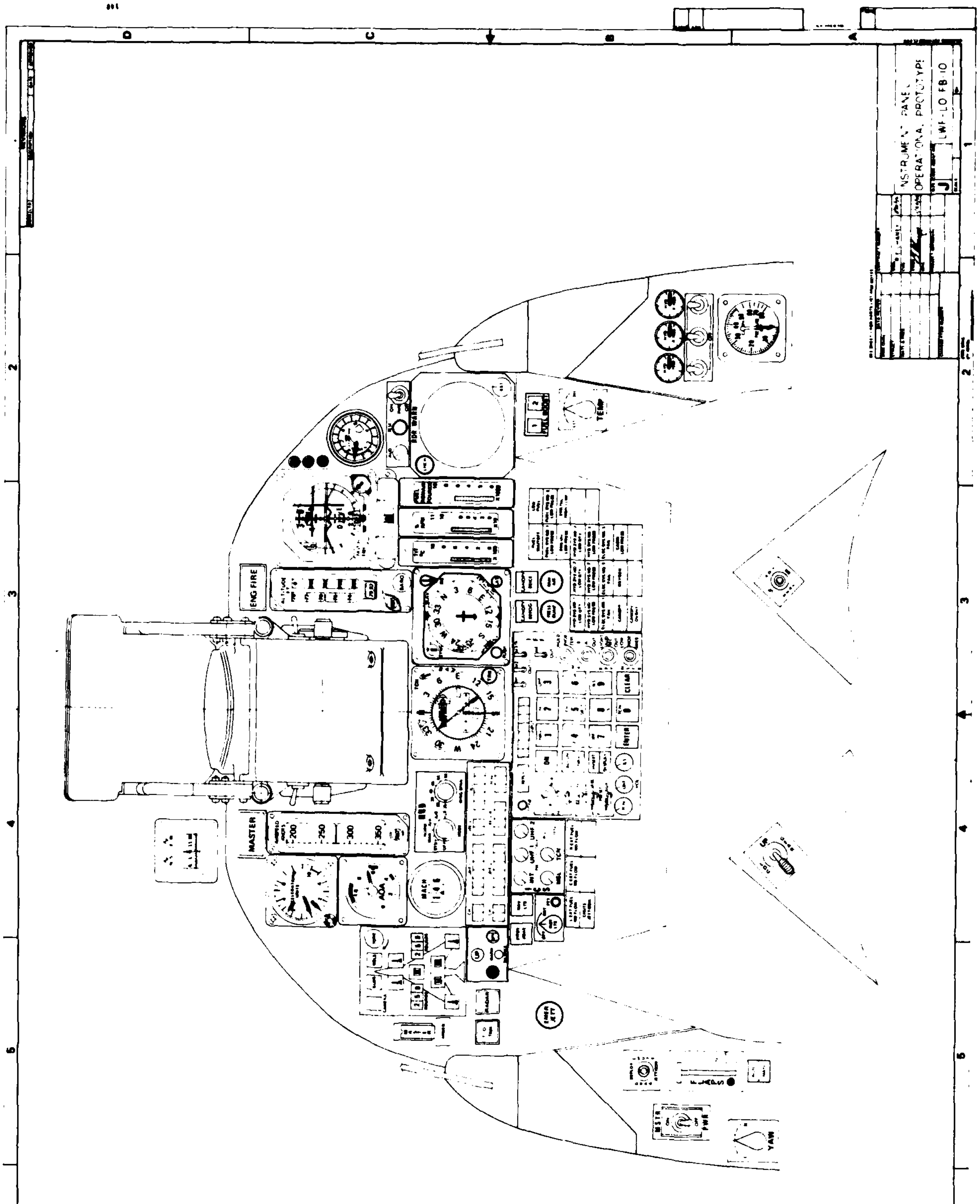

FIGURE 7.03 - ENGINEERING DRAWING OF AIRCRAFT INSTRUMENT PANEL

7.2.2 Mockups

Summary Description: Mockups are full scale models of items of equipment or facilities. Mockups are constructed to evaluate the system design before the manufacture of hardware and are either static or dynamic. Static mockups do not work; dynamic mockups do work.

A static mockup is usually made of inexpensive material such as cardboard with a foam core. The crewstation components are represented by cutouts from engineering drawings or photographs of the hardware or by actual hardware. Figure 7.0-4 illustrates a static mockup utilizing engineering drawings of control and display hardware.

A dynamic mockup has controls and displays that actually operate . The degree of complexity of a dynamic mockup can vary from relative simplicity to almost as complex as a simulator. Figure 7.0-5 illustrates a dynamic mockup with working control and display hardware.

When Used: Dynamic mockups are usually constructed late in the design cycle when the design has been developed to a considerable level of detail but before hardware is built. Static mockups may be constructed as early in the design cycle as sufficient information is available.

Product and Purpose: Both static and dynamic mockups are used to take measurements of operator and maintainer reach capabilites, clearance spaces, access openings, and vision capabilities and to compare the measurements with HFE design criteria for verification. Both types of mockups are also used to aid in visualizing three-dimensional problems.

Both types of mockups are used to study the performance of personnel in simulated operational situations. In a static mockup, persons representing operators simulate looking at displays by looking at the drawings of displays glued to the console and simulate operating the controls by touching the drawings of controls. In a dynamic mockup, operators actually perform operational procedures and the equipment responds. Figure 7.0-6 illustrates simulation of task performance in a static mockup.

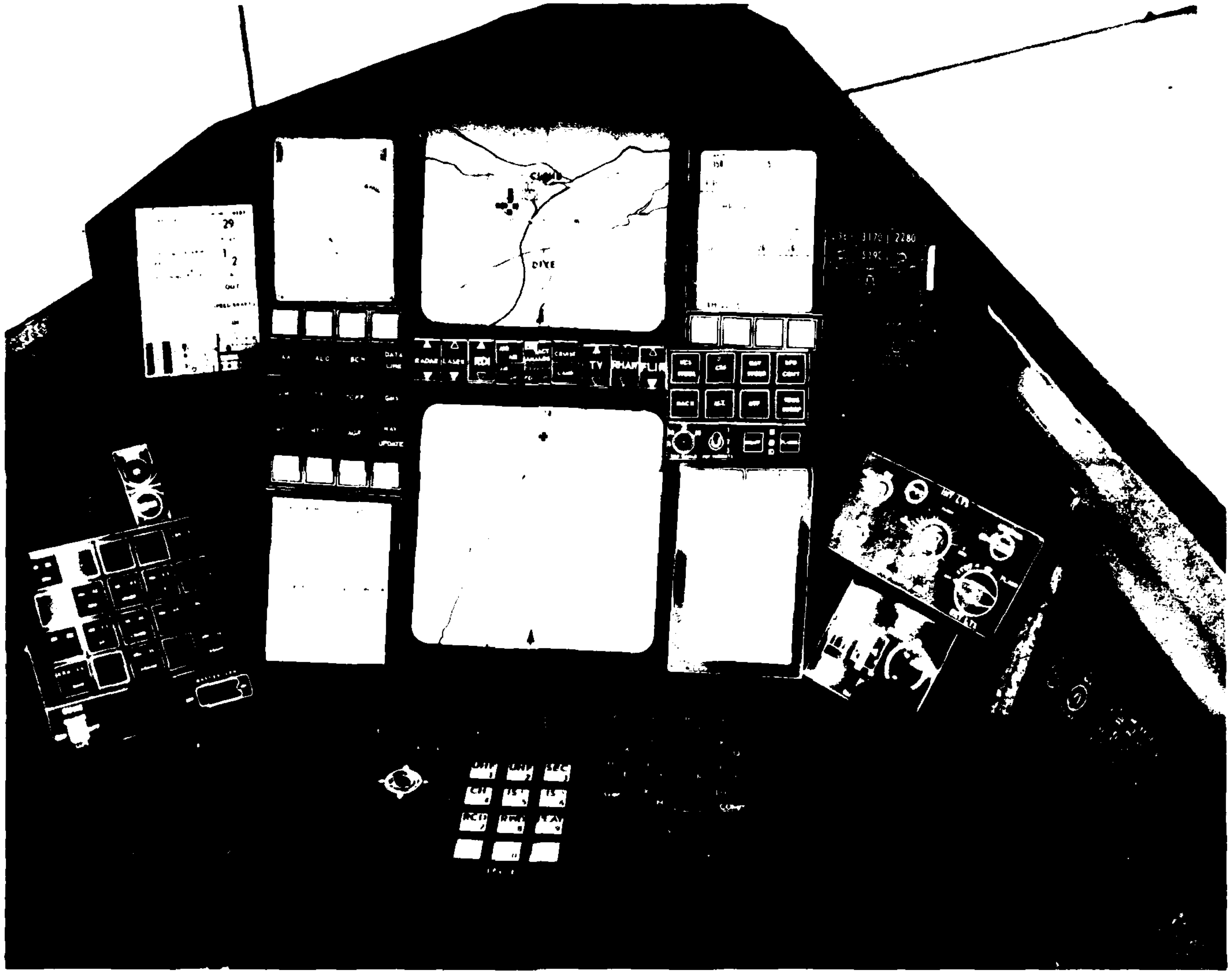

Figure 7.0-4. Static Mockup Utilizing Engineering Drawings

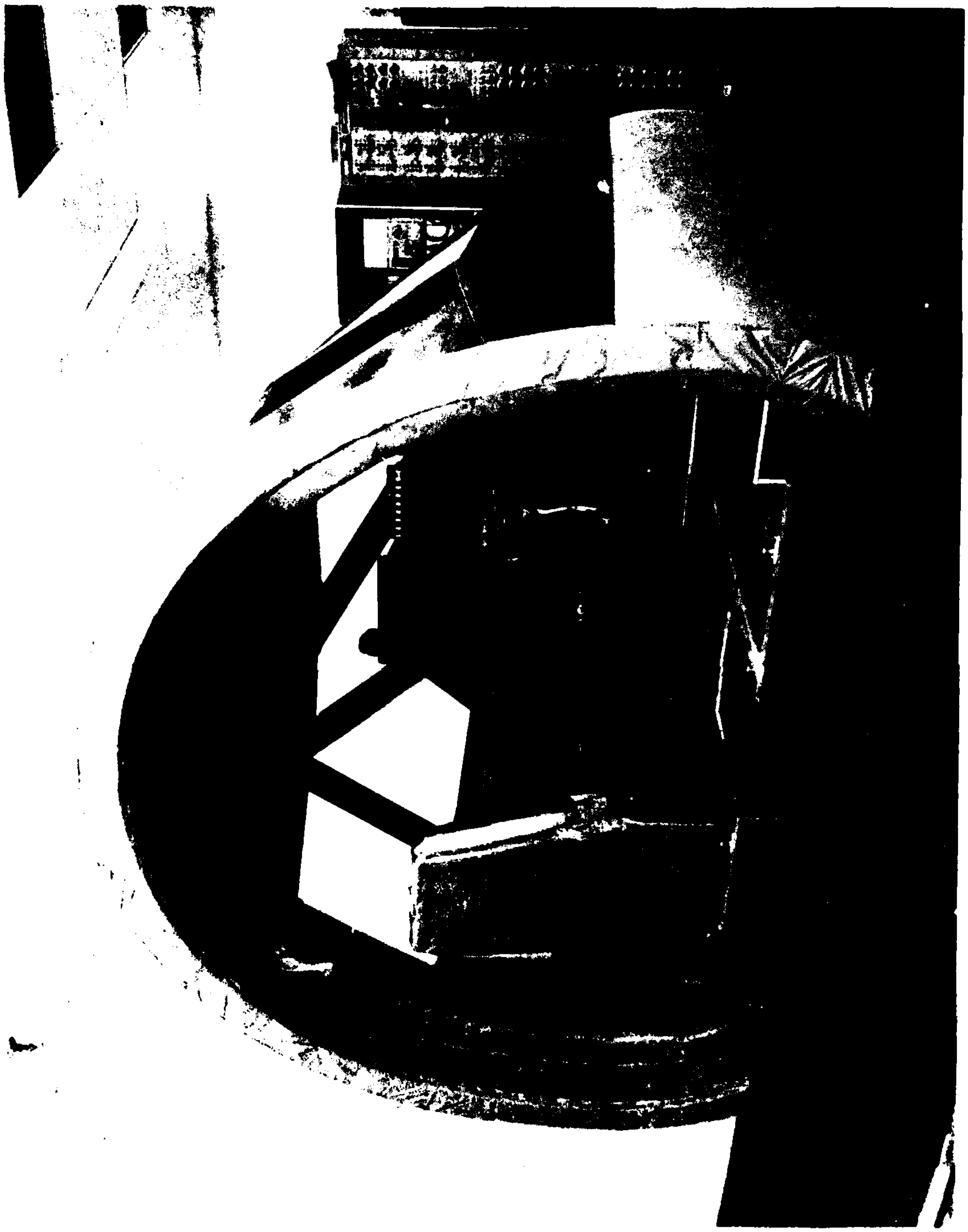

Figure 7.0-5. Dynamic Mockup Utilizing Working Hardware

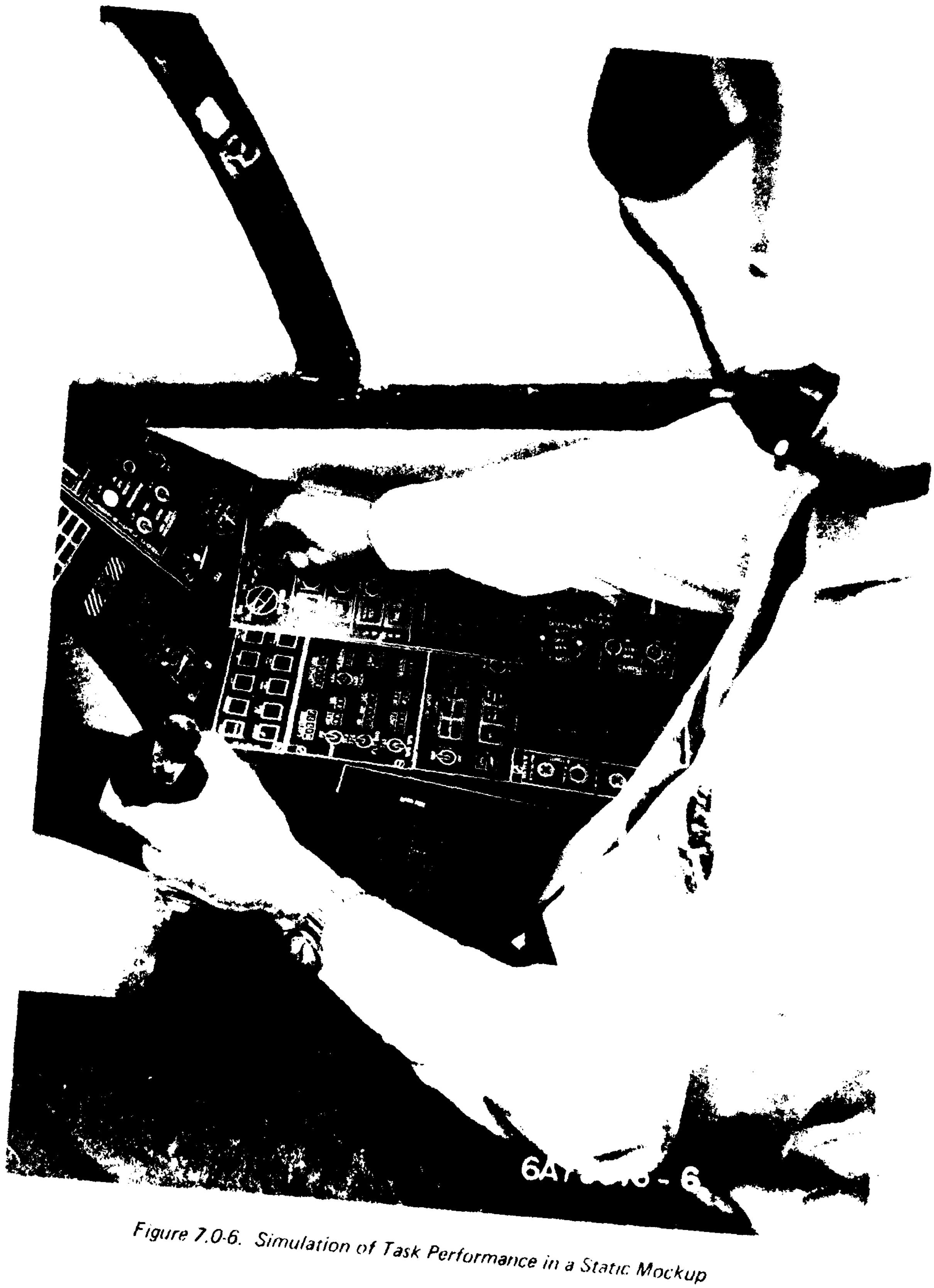

Figure 7.0-6. Simulation of Task Performance in a Static Mockup

Figure 7.0-7. Foam Core Mockup of External Shell of Crewstation in Designers' Work Area

Procedure for Use: A static mockup is initially made with easy to use and inexpensive material. Various thicknesses of plastic foam core filled cardboard sheets plus a hot glue gun and a matte knife are used to build consoles, racks, and complete cockpits. Console panel layout drawings are glued to the foam core cardboard to simulate the real displays and controls. Persons representing operators then simulate the performance of tasks by looking at the drawings of displays and by touching the drawings of controls with hands or feet (see Figure 7.0-6). A technique has been developed at the Boeing Company for hardening a foam core cardboard mockup with fiber glass so that it can be used for more vigorous testing than an unhardened mockup.

As the system design progresses, a static mockup with closer tolerances is constructed from plywood. Plywood is more expensive but is more rigid and durable. The static plywood mockup with drawings of console panels is later converted to a dynamic mockup by replacing the drawings with actual working displays and controls.

At Boeing, foam core mockups of the external shell of a crewstation have been constructed early in the design phase and placed in the area where the designers are working (see Figure 7.0-7). This technique has proved very helpful in assisting designers to visualize the human-machine interfaces.

Advantages: Mockups allow static or dynamic evaluation in three dimensions of a number of human-machine interfaces before hardware is built. Operators can be observed and interviewed. Lighting and sound measurements can be taken. Operational procedures can be verified. Dynamic mockups provide greater realism to these evaluations than static mockups.

Limitations: 1) Mockups can be expensive.

2) Mockups are frequently not constructed until late in the design cycle.

3) Personnel used to simulate operator in tests will probably not be anthropometrically representative of the intended operator population.

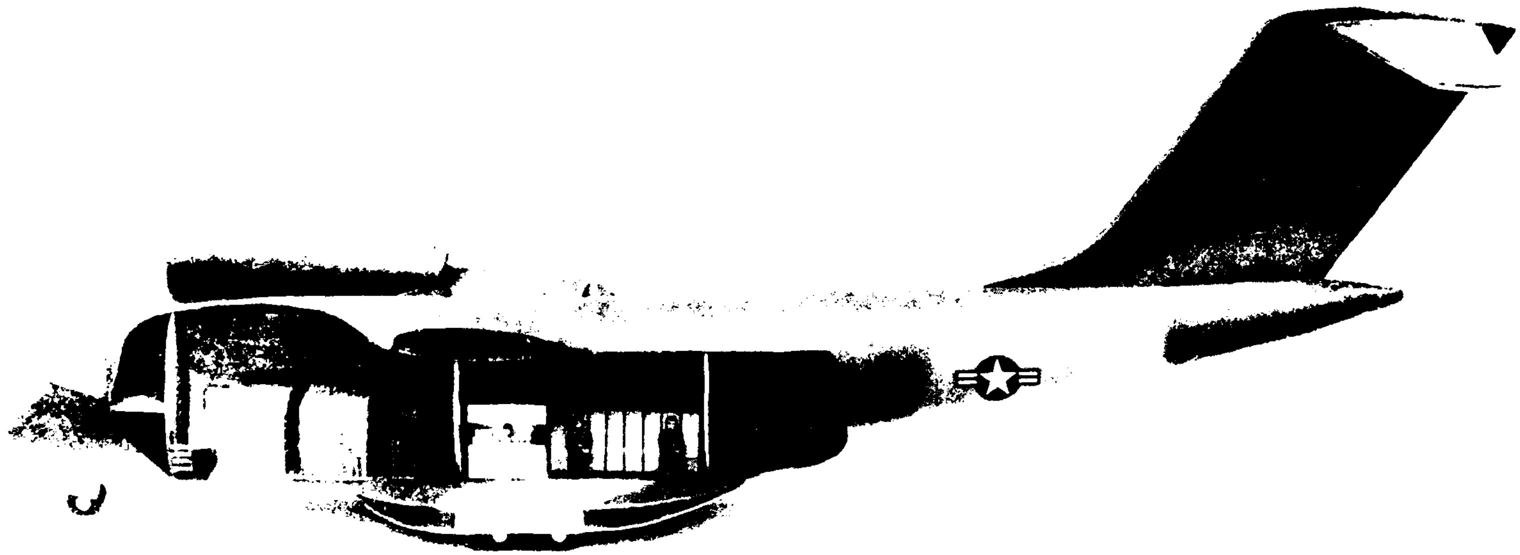

Figure 7.0-8. Scale Model of Aircraft

7.2.3 Scale Models

Summary Description: A scale model is a representation of a component, subsystem, or system which is built to less than full scale, for example, to 1/10 scale. Figure 7.0-8 illustrates a scale model of an aircraft.

When Used: Scale models can be constructed at any time in the design development cycle that the necessary data is available. A scale model may be constructed because a full scale model would be too cumbersome, too expensive, or too complicated. Scale models are more likely to be built before hardware but might be built for demonstration purposes after the hardware exists.

Product and Purpose: Scale models allow viewing of a system in three dimensions. They allow the HFE specialist to see the whole system at once which might not be possible in full scale. They also allow evaluation of some logistics problems.

Procedure for Use: The HFE specialist looks at the scale model and visualizes the activities which the personnel will perform to gain a better understanding in three dimensions of the human-machine interface. The specialist may also use the scale model to demonstrate to others some aspect of operator or maintainer activities.

Advantages: 1) Scale models can be more useful for visualizing a crewstation design in three dimensions than a drawing.

2) Scale models can be cheaper to build and more easily transported and stored than mockups.

Limitations: Scale models cannot be evaluated as to whether the hardware meets HFE design criteria because there are no HFE measurement or evaluation tools such as small three-dimensional manikins available for this application.

7.3 Design Techniques to Represent the Operator

The technique described below represents the operator.

7.3.1 Manikins

Summary Description: A manikin is a flat, transparent plastic representation of a human. It represents the two-dimensional anthropometric characteristics of a human such as height and arm length as seen from the side. The manikin has movable parts so that it can be arranged in various positions. Figure 7.0-9 illustrates a manikin.

When Used: Manikins are used in the drawing preparation process or after drawings are completed but before hardware is built.

Product and Purpose: The manikins are used to prepare drawings and to evaluate drawings. Problems such as controls which cannot be reached, reach interference, and restrictions of personnel movement, entry, and exit can be identified.

Procedure for Use: A set of manikins must be purchased or constructed in a range of sizes and scales. For maximum flexibility, a large number of sizes, shapes, and scales which correspond with the scales in which engineering drawings are usually made will be required (at least 1/10 and 1/4 scales).

To evaluate a drawing, the HFE specialist places the manikin on the crewstation in the drawing and moves the parts of the figure into various lifelike positions. As the manikin is moved through the various positions, the specialist checks for reach availability, access, and interference. To a limited extent, vision can be checked. Manikins representing theoretical persons with perfect 2nd and 98th percentile dimensions can be used to determine if the design is compatible with each of the anthropometric dimensions of the smallest and largest persons in the proposed user population. Because the manikins are made of clear plastic, it is easy to see the amount of interference or overlap if a manikin's dimensions exceed the space provided on the drawing.

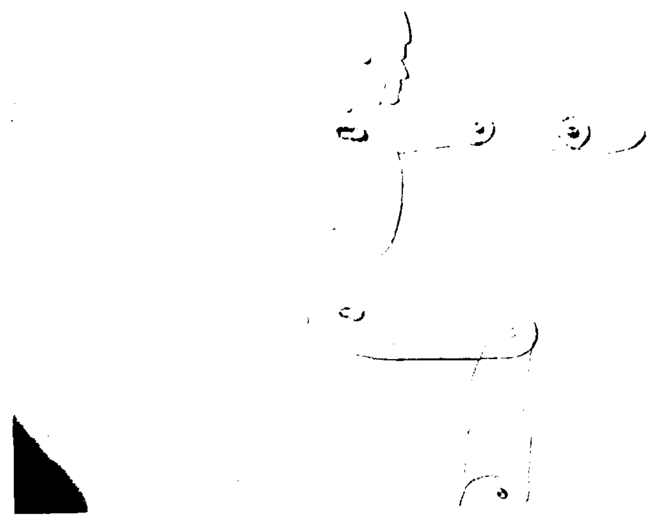

Figure 7.0-9. Manikin

In creating a design, the HFE specialist uses a manikin as a template and draws an outline around it. This technique can also be used to prepare illustrations of various sizes of personnel in critical positions.

Reference 15 is a good source of information about the uses of anthropometry and manikins in HFE design.

Advantages: Manikins are very cost effective in avoiding or identifying problems on drawings. Although a full set of sizes and shapes of manikins will cost several hundred dollars, this expenditure pays off by allowing more accurate design.

Limitations: 1) Manikins cannot be made so that they move in all the ways that humans move.

2) Manikins are not usually representative of the combinations of anthropometric dimensions which any actual operator population will have. They represent theoretical persons with perfect 2nd or 98th percentile dimensions, for example.

3) Manikins are more readily available representing male than female dimensions.

4) Since manikins are an approximate tool, they cannot be the only means used to determine HFE criteria design compliance or deviation from criteria.

5) Manikins are not available in as wide a range of scales as engineering drawings which are stored in computer data banks and retrieved with aperture cards.

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15. Roebuck, J. A., Jr., Kroemer, K. H. E., and Thomson, W. G., Engineering Anthropometry Methods, Wiley, New York, 1975.

7.4 Design Techniques to Represent the Operator Interacting With the Hardware

The design techniques described in this section represent the operator interacting with the hardware.

7.4.1 Visibility Diagrams

Summary Description: Visibility diagrams are drawings of the area an operator can see externally when in a crewstation. This area is called the operator's vision envelope and it is usually depicted by preparing several diagrams of the operator in front of a console or other instruments and controls. Figure 7.0-10 illustrates a visibility diagram.

Visibility diagrams show actual views from the operator's eyes. The diagrams show the maximum field of vision of the operator from side to side ($\pm$180 degrees) and up and down ($\pm$90 degrees).

When Used: A visibility diagram is prepared as soon as the design details are available to make its preparation possible and before hardware is built.

Product and Purpose: Visibility diagrams are used to determine what operators can and cannot see external to the crewstation. They are used in cockpit design, for example, to determine where window posts appear in the pilot's view of the runway during landing approaches from various angles.

Procedure for Use: The HFE specialist uses drawings of the operator in the crewstation and measures the angles from the operator's eye reference point to significant items such as windows, displays, and controls. Angles to several points on each of the significant items are measured and plotted in order to approximate the shape of the item. Most straight lines are plotted as curved lines. Straight lines below the horizontal plane curve up and above the plane curve down.

Advantages: Visibility diagrams can avoid the cost of a mockup constructed specifically to evaluate operator vision.

Limitations: Visibility diagrams can be complex to prepare.

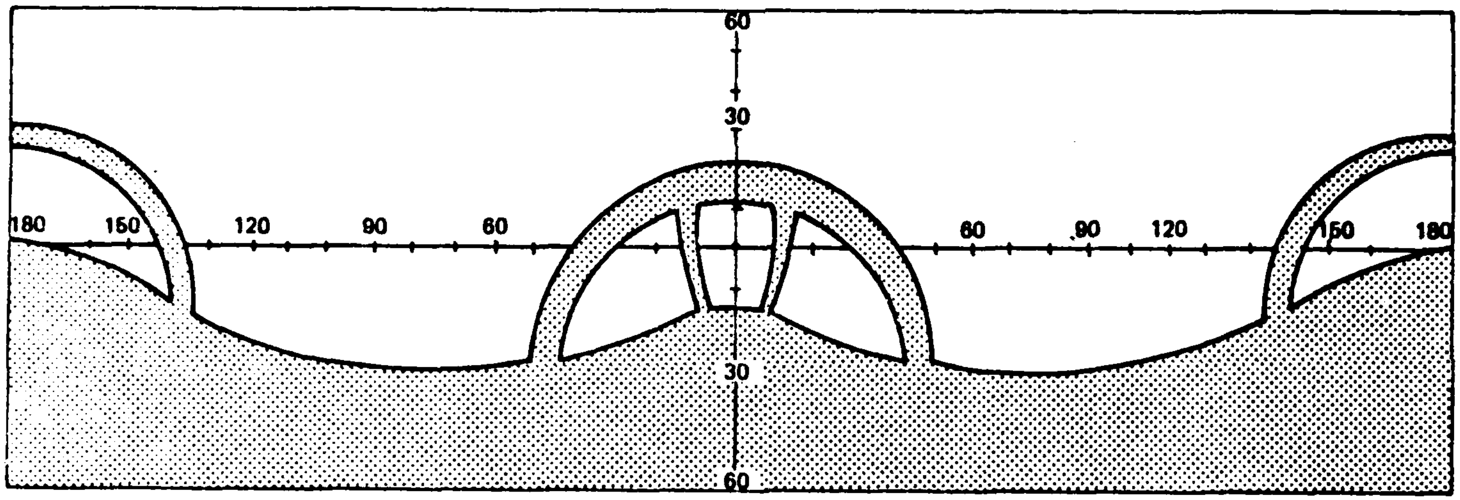

FIGURE 7.0-10 - COCKPIT VISIBILITY DIAGRAM

7.4.2 Reach Envelopes

Summary Description: A reach envelope drawing shows the area an operator can reach. Controls must be placed within the area designated by the reach envelope for the operator to be able to use them. The operator of interest is usually the smallest operator from the anticipated operator population defined as an operator with 2nd percentile dimensions. Figure 7.0-11 illustrates a reach envelope.

When Used: Reach envelopes are prepared as soon as the necessary design details are available to make their preparation possible and before hardware is built.

Product and Purpose: Reach envelope templates are prepared and used to evaluate engineering drawings. A determination is made of whether or not the smallest person in the anticipated operator population will be able to reach the controls or if it is necessary to move the controls and the operator closer together. Reach envelopes are particularly useful for evaluating large consoles with side wraparound panel areas or vertical panels areas which project above the operator's eye reference point.

Procedure for Use: The HFE specialist must obtain reach envelope data. Ideally, data from a group of operators representing the anthropometric dimensions of the anticipated user population will already be available. Reach capability data will have been taken for each of these operators under various conditions such as wearing a pressure suit, with the seat back angle varied, with and without shoulder restraint, and in various directions and heights in relation to a seat reference point. Using this data, statistical computations can be made and data points selected for preparation of the reach envelope. If the data is not available, the HFE specialist will have to adapt existing data or generate new data.

The specialist then constructs reach envelope templates. After the templates are constructed, the specialist places them over the engineering drawings to determine which points on the crewstation panels are within the operator's reach limits.

Advantages: 1) Reach envelope drawings may eliminate the need to construct a mockup specifically to evaluate operator reach.

2) Reach envelope evaluation can be performed before hardware is built.

Limitations: 1) Existing statistical data used to describe the typical operator with a 2nd percentile functional reach does not include sufficient data for females.

2) A considerable amount of time is required to obtain and process reach envelope data and to construct reach templates.

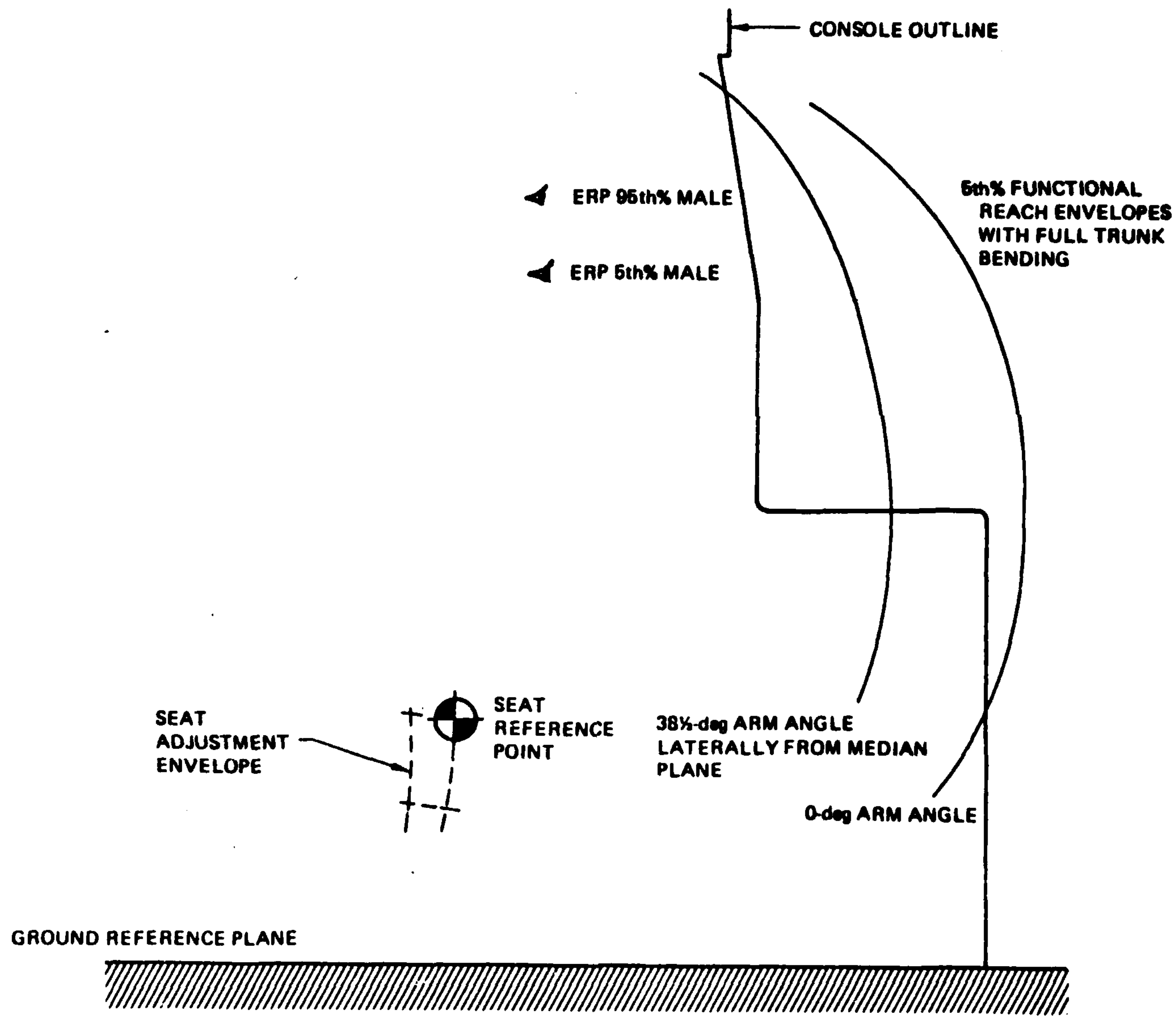

FIGURE 7.0-11 - REACH ENVELOPE

8.0 Design Techniques Using Computers

With the widespread use of computers, techniques have been devised to automate time-consuming HFE tasks. Techniques have also been developed to do things which were previously not possible.

In order to employ any of the techniques using computers, it is necessary to have access to or obtain the computer hardware and accessory equipment required to implement the technique. It is also necessary to obtain the computer software (computer programs) and to have the software modified to some extent for each individual computer facility.

The HFE specialist must learn the capabilities of the technique. The specialist must obtain or generate the required data and prepare it for entry which may involve some kind of coding. The specialist must also enter the data and request, receive, and interpret outputs.

The techniques using computers vary in a number of ways. They address a variety of questions using different theoretical approaches. Some are harder to learn to use or to use than others. Some perform more complex analyses than others. Some are more expensive to use than others. Some are very difficult to transfer from one computer facility to another.

The discussion which follows briefly describes the techniques. The subjects addressed by the techniques are summarized in Table 8.0-1. References 16 and 17 contain detailed theoretical and technical analyses

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16. Greening, C. P., Analysis of Crew/Cockpit Models for Advanced Aircraft, ADA054957, Autonetics Div., Rockwell International, Naval Weapons Center, China Lake, Ca., February 1978.
17. Pew, R. W., Feehrer, C. E., and Baron, S., Critical Review and Analysis of Performance Models Applicable to Man-Machine System Evaluation, AD-A038-597, Bolt, Beranek and Newman, Inc., Air Force Office of Scientific Research, March 1977.

of a number of the computer models. More information about the models can be obtained from the source documents referenced in the detailed descriptions of the techniques in this section and from the personnel at the implementation locations identified in this section.

COMPUTER TECHNIQUES*	SUBJECTS ADDRESSED BY TECHNIQUE														GRAPHICS		
	CONTROL-DISPLAY SIZE	SPECIFIC TASK PERFORMANCE	PERFORMANCE TIMES	WORKLOAD	SYSTEM PERFORMANCE	INTERNAL VISION CAPABILITY	EXTERNAL VISION CAPABILITY	VISION INTERFERENCE	REACH CAPABILITY	CONTROL RELOCATION	REACH INTERFERENCE	ESCAPE CAPABILITY	PERCENTAGE OF CREW EXCLUDED	DIMENSIONAL COMPLIANCE WITH MILITARY STANDARDS	GRAPHIC DISPLAY	INTERACTIVE DESIGN LAYOUT CAPABILITY	GRAPHIC ILLUSTRATION PRINTOUT
CAD							X	X	X			X					X
CAPE									X			X	X				
CAR									X	X			X				
CGE						X		X	X		X			X			X
COMBIMAN							X		X		X		X		X	X	X
CUBITS	X																
HECAD		X	X						X						X	X	X
HOS		X	X	X	X					X							

*ACRONYMS ARE DEFINED IN SECTION 8.

TABLE 8.0-1 - SUBJECTS ADDRESSED BY COMPUTER TECHNIQUES

8.1 Techniques Representing the Operator Interacting With the Hardware/Software

All of the techniques using computers are representations of the operator interacting with the hardware/software.

8.1.1 CAFES (Computer Aided Function Allocation and Evaluation System)

Summary Description: CAFES is the name given to a collection of computer programs for HFE analysis and HFE design. CAFES was developed for the Naval Air Development Center by The Boeing Company (Reference 18) and consists of four modules. Two of these modules are described in the analyst's guide (Reference 2). One is described later in this section and one is briefly discussed below.

The CAFES modules in the analyst's guide are FAM (Function Allocation Model) for evaluating the effect on a system of allocating the functions in various different ways to crews and to hardware and WAM (Workload Assessment Model) for evaluating crew workload.

The CAFES module described later in this section is CAD (Computer Aided Design) for evaluating crewstation designs.

The fourth CAFES module is the CAFES/CGE Interface which allows use of CAFES command language for data input to CGE (Cockpit Geometry Evaluation). CGE is described later in this section.

For all of the CAFES modules, the same type of communication is used to begin and end processing, to call up a particular module, and to obtain output. These common features make it easier for the HFE specialist to use the various modules.

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2. Geer, C. W., Analyst's Guide for the Analysis Sections of MIL-H-46855 D180-19476-1, Boeing Aerospace Company, Naval Air Development Center, Warminster, Pa., 30 June 1976.
18. Edwards, R. E., Renshaw, K. S., Healy, M. J., and Atkins, R. A., Computer Aided Function Allocation Evaluation System (CAFES), ADA033856, Boeing Aerospace Company, 1976.

The information obtained from the outputs of one CAFES module can be used in preparing the inputs for another module. For example, if the underlying cause of a high workload condition identified by a WAM simulation is attributed to the level of automation of a system or to the system's operational procedures, this information can be used to alter the number and type of controls and displays or to modify control and display arrangements on one or more panels. If the workload analysis reveals low workload levels for extended periods of time, this information can be used to eliminate one or more crewstation positions in the FAM model. Errors in crewstation design such as the omission of a required control or display may be detected when preparing WAM input data. These same design errors may also be reflected by higher workloads in WAM.

8.1.2 <u>CAD (Computer-Aided Design)</u>

<u>Summary Description</u>: CAD uses a computer to simulate an operator reaching for controls, looking out the windshield, and escaping from a crewstation of a specific design.

CAD computes: the distance between the operator's shoulder or other reference point and the controls to be used, the operator's line of sight out the windshield, and the operator's escape path. CAD prints out graphic views of the crewstation in addition to the numerical data.

From a CAD simulation, the HFE specialist can determine whether an operator of a specific size can reach all the controls, see out the windshield, and escape from the aircraft. The specialist can also identify obstacles obstructing vision or escape. A reach envelope plot is illustrated in Figure 8.0-1. Figure 8.0-2 is a graphic printout of a cockpit escape path and obstructions in the escape path.

CAD does not address specific task performance, performance times, workload, system performance, internal vision, reach obstruction, control relocation, percentage of operator population accommodated or excluded by crewstation dimensions, or crewstation dimensional compliance with specific military standards. CAD does not have a graphic display or interactive design layout capability.

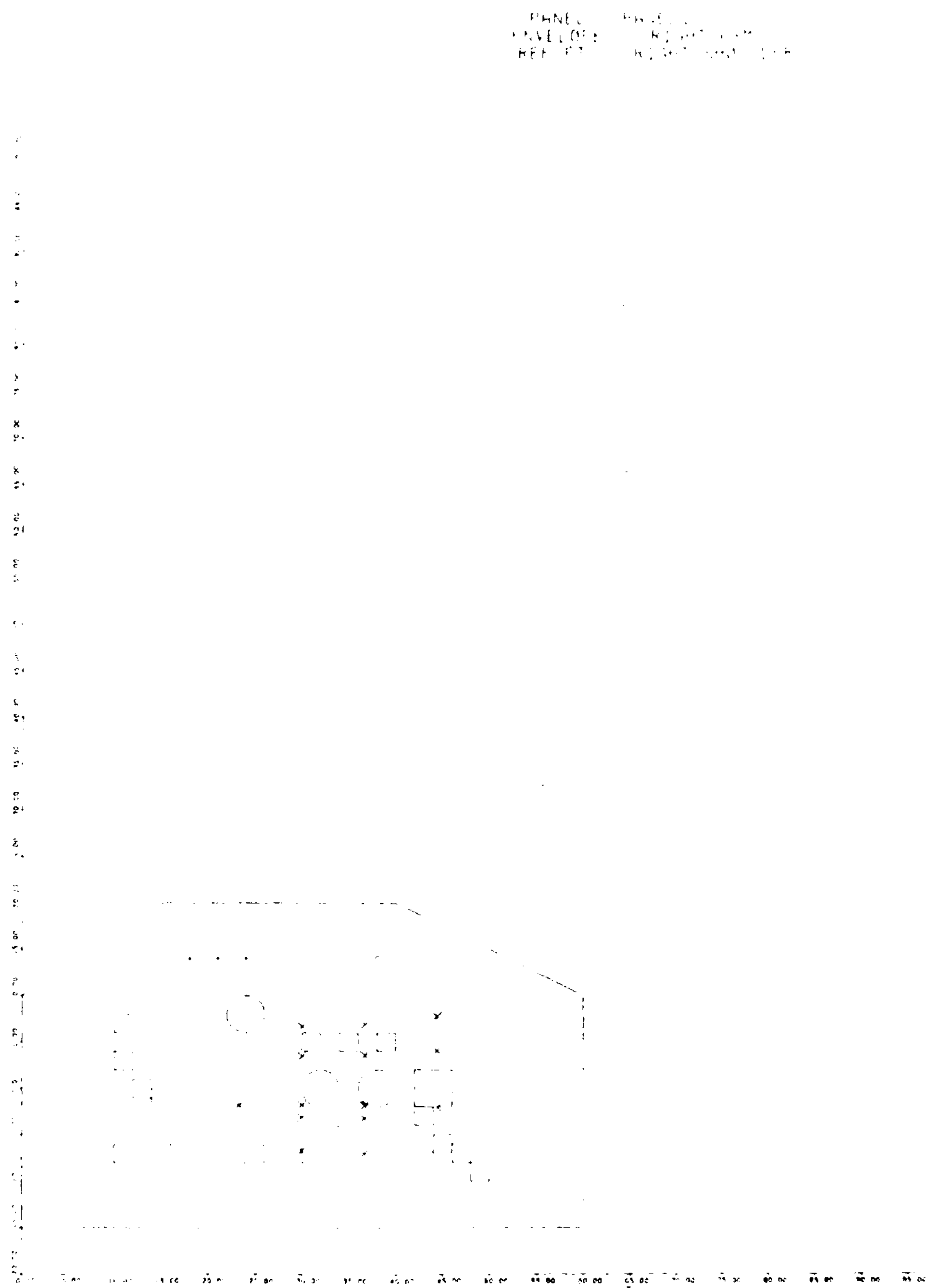

FIGURE 8.0-1 - CAD: REACH ENVELOPE PLOT

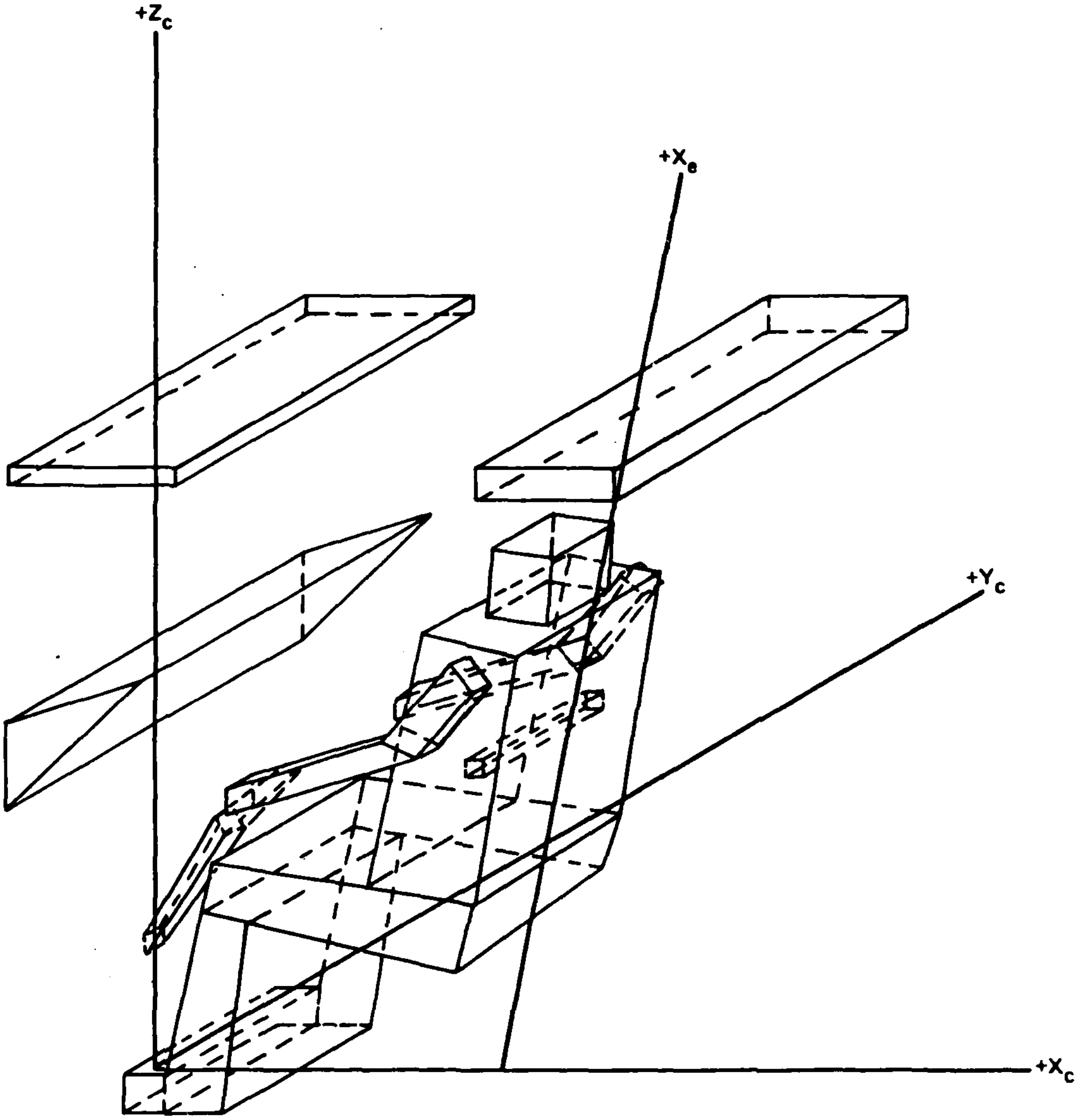

FIGURE 8.0-2 - CAD: PRINTOUT OF COCKPIT ESCAPE PATH AND OBSTRUCTIONS

When Used: CAD is used as soon as a preliminary design is developed to the considerable level of detail to provide the required data or after a final design is completed but before hardware is built.

Product and Purpose: CAD produces the following products:

1) a reach analysis from which the HFE specialist can determine whether control panel elements can be reached and what any obstacles are

2) an external vision analysis from which the HFE specialist can determine the limits of external vision from a crewstation and whether external vision is obstructed by any part of the crewstation

3) an escape analysis from which the HFE specialist can determine whether a crewstation design complies with the HFE design requirement foran unobstructed cylinder along the escape path with a minimum square cross section of 30 x 30 inches and what any obstructions are

4) the following graphic illustrations which the HFE specialist can use to evaluate the design: control and display panels showing panel boundaries, boundaries for groups of functionally related controls and displays, and shape and location of each instrument and control; plots of regions visible to crewmembers; and plots of escape envelopes.

Procedure for Use: The HFE specialist must learn to use CAD. The specialist must then assemble or generate the required data, prepare it for entry, and enter it. All data is entered on punched cards. A large quantity of data is required, and considerable coding is necessary.

The following data must be entered: geometry data for controls and displays and for panels, information about groups of functionally related controls and displays, specific reference points of design significance within the crewstation, a name for each geometric feature, and a set of coordinate points to establish the shape and location of the feature relative to the primary aircraft coordinate system.

For a reach analysis, the HFE specialist must first construct reach envelopes using procedures described in Section 7. The specialist then enters the reach envelope data and a crewstation panel definition.

For an escape analysis, the specialist must enter data describing an escape volume, a set of potential obstructions, and an escape path.

For a vision analysis, the specialist must enter the aircraft coordinates describing all windows, all structural features of the cockpit that may obstruct a crewmember's vision, a design eye reference point within the crew station, the name of the crewmember for whom the vision analysis will be performed, and the name of a previously defined reference point which specifies the position of the crewmember within the crewstation. Obstructions may include vision limiting points along the perimeter of windows, window frames and rails, sunshields, handles, forward panels, and equipment housings that project into the field of view.

Advantages: 1) CAD produces good graphic illustrations.

CAD performs useful analyses which are too complex to perform by hand.

Limitations: 1) CAD is expensive to use.

2) CAD is difficult for the HFE specialist to learn to use and time-consuming to use.

3) CAD has not yet been transferred from one computer facility to another.

Technical Details: Computer programs are written in FORTRAN IV. CAD is implemented on a CDC 6600 computer with KRONOS 2.1 Operating System and RUN Compiler.

History and Source: CAD was developed for the Naval Air Development Center by The Boeing Company (Reference 19). The current version was completed in 1974. CAD is implemented at NADC, Warminster, Pa.

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19. Edwards, R. E., Curnow, R. P., and Ostrand, R. A., Computer Aided Design (CAD) User's Manual, D180-20247-5, Boeing Aerospace Company, Naval Air Development Center, March 1978.

8.1.3 CAPE (Computer Accommodated Percentage Evaluation)

Summary Description: CAPE uses a computer to simulate a series of operators with different combinations of arm length, leg length, and other anthropometric characteristics representative of an actual population of proposed operators. It also simulates a proposed crewstation design.

CAPE compares the measurements and other characteristics of these operators with the dimensions of the crewstation and the location of the controls and records the discrepancies.

From a CAPE simulation, the HFE specialist can determine the actual percentage of a proposed operator population who can fit into, operate, and escape from a proposed crewstation design. The specialist can also determine how many operators are excluded from the crewstation design by any specified anthropometric dimension or by any specified crewstation dimension.

CAPE does not address specific task performance, performance times, workload, system performance, vision, reach interference, control relocation, or crewstation dimensional compliance with specific military standards. It does not have a graphic display or interactive design layout capability and does not produce graphic illustrations.

When Used: CAPE is used as soon as a preliminary design is developed to the level of detail to provide the required data or after the final design is completed but before hardware is built.

Product and Purpose: CAPE produces an exclusion demonstration from which the HFE specialist can determine what percentage of a potential operator population will be excluded from a crewstation design with respect to each specified anthropometric feature of the crew.

CAPE produces a crewstation analysis from which the HFE specialist can determine the percentage of the operator population that will be excluded from a crewstation design based on the dimensions of the crewstation.

Procedure for Use: The HFE specialist must first learn to use CAPE and then assemble or generate the required data. The specialist then enters the data with a computer terminal keyboard in response to prompts from the computer program. Previously entered data can also be retrieved from computer data files.

For a crewstation exclusion analysis, the specialist enter the following data: seat-cockpit parameters, control locations, means and standard deviations for the operator dimensions, correlations between the operator dimensions, number of operators to be tested, and number of operator dimensions to be considered in the analysis.

For a population exclusion analysis, the specialist enters statistical data about operator dimensions.

Advantages: 1) CAPE is one of the few techniques which computes the percentage of a proposed operator population which will be accommodated by or excluded from a proposed crewstation design.

2) CAPE is one of the less expensive techniques using computers.

Limitations: 1) CAPE is somewhat difficult to use.

2) CAPE is not easily transportable from one computer facility to another.

3) The dimensions of one specific individual cannot be entered into CAPE.

4) Since the CAPE reach analysis does not recognize obstacles, any obstacles will be reached through.

History and Source: CAPE was developed by the Pacific Missile Test Center (Reference 20). The current version was completed in 1975. CAPE is implemented at PMTC, Point Mugu, Ca.

Technical Details: CAPE is written in Super FORTRAN.

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20. Bittner, A. C., Computerized Accommodated Percentage Evaluation (CAPE) Model for Cockpit Analysis and Other Exclusion Studies, TP-75-49/TIP-03, Pacific Missile Test Center, Point Mugu, Ca., December 1975

8.1.4 CAR (Crewstation Assessment of Reach)

Summary Description: CAR uses a computer to simulate a series of crewmembers sitting in the seat of a crewstation of a specific design, adjusting the seat at the design eye point, and reaching for the controls with hands and feet. The simulated crewmembers have different combinations of arm length, leg length, and other anthropometric characteristics representative of 1964 Navy pilots or any other group for which an anthropometric data base is available.

CAR computes the percentage of crewmembers who can position themselves at the design eye point, reach the controls, and have adequate head clearance. CAR also computes the amount of relocation, if any, required for controls so that a specified percentage of crewmembers can reach them.

From a CAR simulation, the HFE specialist can determine how many crewmembers can fit in the crewstation and operate the system. The HFE specialist can also determine the amount of control relocation required.

CAR does not address performance of specific tasks, performance times, workload, system performance, vision or reach obstruction, escape, or crewstation dimensional compliance with specific military standards. CAR does not have a graphic display or interactive design layout capability and does not print graphic illustrations.

When Used: CAR is used as soon as a preliminary design is completed to the level of detail to provide the required data or after the final design is completed but before hardware is built.

Product and Purpose: CAR produces the following data:

1) the percentage of crewmembers that can be positioned to the design eye point

2) if a head clearance check is performed, the percentage of crewmembers that have a head clearance distance greater or equal to the specified distance

3) the percentage of crewmembers that can reach all primary controls, after being positioned as close to the design eye point as possible

4) the percentage of crewmembers that can be positioned to or close to the design eye point and can reach all primary controls

5) the distance that each control must be moved so that the crewstation will accommodate the user specified percentage of crewmembers.

Procedure for Use: The HFE specialist must learn to use CAR and then assemble or generate the required data. There is no special coding or special language to learn. The specialist enters the data with a computer terminal keyboard in response to prompts from the computer program. The following data must be entered:

1) crewstation description
2) number of crewmembers to be simulated (1 to 400)
3) design eye point and seat data:
   a) seat back angle in degrees
   b) seat pan angle in degrees
   c) coordinates of the neutral seat reference point
   d) coordinates of the points defining the horizontal and vertical limits of seat adjustment
4) primary control data and details on reach analysis:
   a) control name
   b) coordinates of control point
   c) hand or foot control
   d) right or left hand or foot or both
   e) type of hand grip: clenched, fingertip grip, or extended fingers
5) data for head clearance check, if wanted:
   a) coordinates of the point on the canopy directly above the design eye point
   b) helmet thickness (distance between top of head and top of helmet)
   c) minimum clearance distance

Advantages: 1) CAR is one of the few techniques which computes the percentage of proposed crewmembers who will be accommodated by or excluded from a proposed crewstation design.

2) CAR is one of the less expensive techniques using computers.

3) CAR is quick and easy for the HFE specialist to use.

4) CAR has been transferred from one computer facility to another a number of times.

Application Example: CAR has been used by 10 NADC contractors including General Dynamics, it has been used to evaluate F-16 designs, and NASA has used it.

Limitations: 1) The dimensions of a specific individual cannot be entered into CAR.

2) Since the CAR reach analysis does not recognize obstacles, any obstacles will be reached through.

History and Source: CAR was developed for the Naval Air Development Center by The Boeing Company (Reference 21). The current version was completed in 1976. CAR is implemented at NADC, Warminster, PA. Additional development for NADC by Analytics is in process and will be completed in 1980.

Technical Details: The computer programs are written in FORTRAN IV and implemented on a CDC 6600 computer with KRONOS 2.1 Time Sharing System and FORTRAN Extended Compiler FTN 4.4. The human model is a simplified link model with joint angular limits modeling those of a seated operator under restrained (shoulder harness locked) and unrestrained condititon. The model simulates human reach.

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21. Edwards, R. E. et al, Crewstation Assessment of Reach (CAR) User's Manual, D180-19321-1, Boeing Aerospace Company, Naval Air Development Center, April 1976.

8.1.5 CGE (Crewstation Geometry Evaluation)

Summary Description: CGE uses a computer to simulate an operator looking at displays and reaching for controls in a specific crewstation design. CGE also compares the dimensions and other characteristics of the crewstation with the requirements of specific military standards.

CGE detects visual and reach interference, determines whether the fully restrained operator can reach the controls, and detects noncompliance of crewstation dimensions with military standards for two-place fixed-wing aircraft.

From a CGE simulation, the HFE specialist can determine whether the operator can see the displays and reach the controls and whether the design complies with military specifications and standards. The HFE specialist can also determine what specific items obstruct the line of sight, what specific items interfere with operator movement and how much, and which items do not comply with military standards.

CGE does not address performance of specific tasks, performance times, workload, system performance, external vision, control relocation, escape, or percentage of the operator population which will be accommodated by or excluded from a proposed crewstation design. CGE does not have a graphic display or interactive design layout capability.

There is a CAFES/CGE interface module which simplifies the input data process by allowing the CAFES command language to be used (Reference 19).

When Used: CGE is used as soon as a design is developed to the considerable level of detail required or after the design is completed but before hardware is built.

19. Edwards, R. E., Curnow, R. P., and Ostrand, R. A., Computer Aided Design (CAD) User's Manual, D180-20247-5, Boeing Aerospace Company, Naval Air Development Center, March 1978.

Product and Purpose: The HFE specialist receives:

1) a list of body segment planes and crew station planes that intersect the operator's line of sight
2) a list of the body segments and crew station geometry components that have interfered with operator movement and the depth of penetration for each instance of interference
3) graphic illustrations showing the interference between a body segment and another body segment, a control shape, and a cockpit plane.
4) a list of all items which pass or fail the compliance tests with military specifications and military standards relevant to two-place fixed-wing aircraft

The specialist uses this data to evaluate the design.

Procedure for Use: The HFE specialist must learn to use CGE. The specialist must then assemble or generate the required data, prepare it for entry, and enter it. A large quantity of data is required, and considerable coding of data items and input commands is necessary. The following data is required:

1) coordinates for crew station geometry
2) anthropometric characteristics of the operator
3) sequence of tasks to be performed

Advantages: 1) CGE provides good graphic illustrations.

2) CGE performs useful analyses that cannot be done by hand.

3) CGE is the only technique using computers which checks for cockpit geometry compliance with specific military standards.

Limitations: 1) CGE is expensive.

2 CGE is difficult to learn to use and time-consuming for the HFE specialist to use. The very detailed cockpit geometry data required can take two weeks to enter.

3) CGE has not yet been transferred from one computer facility to another.

Application Example: To validate the model, CGE was used to perform an evaluation of the A-7E cockpit. The results of the CGE simulation were compared with A-7E crew interview data and other available human engineering data on the A-7E and were found to be correct for a majority of the tasks in the evaluation .

History and source: CGE was developed for the Joint Army Navy Aircraft Instrumentation Research Program (JANAIR) by The Boeing Company (Reference 22). The current version was completed in 1972. A CAFES/CGE interface was developed for the Naval Air Development Center by The Boeing Company in 1976 (Reference 19). CGE is implemented at NADC, Warminster, Pa.

Technical: The computer programs are written in FORTRAN IV and implemented on a CDC 6600 computer with KRONOS 2.1 Operating System and RUN compiler. The following peripheral equipment is required: card reader, card punch, line printer, CALCOMP plotting device, direct access disk capability and a magnetic tape capability to support the CALCOMP plotting device.

CGE utilizes the very sophisticated BOEMAN model of human movement which reaches around obstacles if possible.

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19. Edwards, R. E., Curnow, R. P., and Ostrand, R. A., Computer Aided Design (CAD) User's Manual, D180-20247-5, Boeing Aerospace Company, Naval Air Development Center, March 1978.
22. Katz, R., Cockpit Geometry Evaluation, Phase II Final Report, Vol. III: Computer Program System, D162-10127-3, The Boeing Company, JANAIR Report 720402, November 1971.

8.1.6 COMBIMAN (Computerized Biomechanical Man-Model)

Summary Description: COMBIMAN uses a computer to graphically reproduce an operator of a specified size on a graphic display screen. It then reproduces controls and displays around the operator as they are laid out with a light pen on the display screen.

When the design is completed, COMBIMAN simultaneously projects two views of the design onto the screen to create a three-dimensional effect, rotates these views to be looked at from any angle, and magnifies selected features. It also simulates and reproduces on the screen a series of operators with dimensions representative of the intended user population.

Using a COMBIMAN simulation, the HFE specialist can design a crewstation directly on the graphic display and then evaluate the design. The specialist can identify problems of external vision, reach, and accommodation of the proposed crewmember population. The specialist can also determine the dimensions crewmembers must have to fit into an existing design.

COMBIMAN does not address specific task performance, performance times, workload, system performance, internal vision, control relocation, escape, or crewstation dimensional compliance with specific military standards.

When Used: COMBIMAN is used during the design process or after a design is completed but before hardware is built.

Product and Purpose: COMBIMAN makes it possible for the HFE specialist to create and evaluate crewstation designs. From the visibility plots the specialist can evaluate the adequacy of external operator vision. From the reach envelopes, the specialist can evaluate the adequacy of operator reach. The specialist can determine how well representative crews of variable size will fit into the crewstation of a proposed or existing design. If a crew must be selected to fit an existing design, the specialist can determine the dimensions the crew must have.

Procedure for Use: The HFE specialist must learn to use COMBIMAN but does not have to learn any special language or coding. The specialist enters data at a computer terminal with a light pen on the CRT display or with the keyboard. The specialist can also prepare data to be punched on cards for entry and storage on magnetic tape or disc or use data which has previously been stored in this way.

The specialist first enters data specifying the dimensions of the operator to be simulated. The dimensions of an actual person can be used, either a potential operator the specialist has the dimensions of or a person from an anthropometric survey, or the specialist can request that the computer program compute hypothetical but realistic dimensions using percentile dimensions from large samples. Data about specific individuals is entered with the keyboard or punched cards. Data from anthropometric surveys has usually already been entered and is stored on computer tapes.

The specialist can either enter all the body dimensions most relevant to the design such as sitting height or arm length or can specify one dimension such as sitting eye height and the computer program will simulate an operator with realistic proportions based on the actual anthropometric data of the population being considered.

After entering the dimensions, the specialist calls up the simulated operator on the CRT screen and lays out the controls and displays around the operator by indicating the corner points of control and display panels with a light pen on the screen. The computer program connects these points by lines. Any available size and location data for panels can be entered with light pen, keyboard, punched cards, magnetic tape, or disc in advance of laying out the design.

After a design has been laid out, a three-dimensional effect can be created by having the computer program project two views of the design simultaneously onto the CRT. The specialist can rotate these views to look at them from any angle and can magnify selected features to aid in evaluating the design.

To get a plot of the external visibility of an operator in a specific crewstation design, the specialist enters data indicating the size of the operator (sitting height, etc.), seat adjustment (vertically, horizontally, or both), head position, and any visual restrictions (helmet, helmet-mounted displays). The resulting visibility plot produced shows the coordinates of the canopy frame in the aircraft coordinate system so that any point in question can be precisely located on the cockpit drawing. This correlation between look-angle and aircraft coordinates allows the specialist to determine the effect of hardware modifications on the external visibility of the pilot.

Advantages: 1) COMBIMAN is the only technique that allows the the HFE specialist to design a crewstation directly on the CRT screen, evaluate the design in three dimensions and from any angle, and determine whether crewmembers from the proposed population can fit into the design.

2) COMBIMAN is easy for the HFE specialist to use.

Limitations: 1) COMBIMAN is expensive.

2) COMBIMAN requires an IBM 2250 computer terminal which has special function keys and an IBM graphics software package. COMBIMAN has not yet been transferred from one facility to another.

History and Source: COMBIMAN was developed by the Aerospace Medical Research Laboratory (Reference 23). The current version was completed in 1978. COMBIMAN is implemented at AMRL, Wright-Patterson Air Force Base, Ohio.

Technical Details: COMBIMAN uses a three-dimensional human model composed of a 33 segment link system with enfleshment ellipsoids.

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23. Evans, S. M., Updated User's Guide for the COMBIMAN, AMRL-TR-78-31, Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio, 1978.

8.1.7 CUBITS (Criticality/Utilization/Bits of Information)

Summary Description: CUBITS is a set of computations for determining the amount of space which should be allocated to a control or display. The computations can be done by hand or they can be computerized.

CUBITS computes the size of the control or display based on how important it is (criticality), how often it is used (utilization), and how much information an operator gets from the display or transfers to the control (bits of information).

From a set of CUBITS computations or a CUBITS simulation, the HFE specialist can determine how big to make a control or display.

CUBITS does not address task or system performance, workload, vision, reach, escape, percentage of operator population accommodated or excluded by crewstation dimensions or crewstation compliance with specific military standards. The computerized version of CUBITS does not have a graphic display or interactive design layout capability and does not print graphic illustrations.

When Used: CUBITS is used during the early design process as soon as the necessary data is available.

Product and Purpose: From the CUBITS computations the HFE specialist can determine precisely what size a control or display should be. The specialist uses this information in laying out controls and displays when designing a crewstation.

Procedure for Use: The HFE specialist must first learn to use CUBITS and then assemble or generate the required data. The specialist then either does the computations by hand or enters the data at a computer terminal.

Advantages: CUBITS provides a systematic and logically derived method for allocating control and display space. Different HFE specialists should come up with approximately the same answers using this technique.

Limitations: CUBITS done by hand is time-consuming.

History and Source: CUBITS was developed for the Naval Air Development Center by Dynamation, Inc. (Reference 24). The current version was completed in 1979. Additional work is being done. CUBITS is implemented at NADC, Warminster, Pa.

8.1.8 HECAD (Human Engineering Computer-Aided Design)

Summary Description: HECAD uses a computer to reproduce on a graphic display the outlines of control and display panels and the components of these panels as the HFE specialist lays them out with a light pen on the graphic display screen.

HECAD computes the distance from an operator's shoulder reference point to each control, simulates operator eye scans and hand movements during task performance, computes probability of successful operator performance, and prints a graphic illustration of the operator's fingertip paths during task performance.

Using a HECAD simulation, the HFE specialist can design a crewstation directly on the graphic display screen and can determine whether an operator can reach the controls, whether operator hand motions are efficient during task performance, and the likelihood of successful operator performance.

HECAD does not address system performance, workload, vision, reach interference or control relocation, escape, percentage of operator population accommodated or excluded by crewstation dimensions, or crewstation compliance with specific military standards.

24. Wherry, R. J., et al, Design Procedure for an Information Transfer Method (CUBITS) of Allocating Panel Area for Aircrew Station Controls and Displays, Dynamation, Inc., Naval Air Development Center, 30 May 1979.

When Used: HECAD is used during the design process, as soon as a preliminary design is developed to the extent that the required data is available, or after a final design is completed but before hardware is built.

Product and Purpose: The HFE specialist is able to create a design and to revise the design directly on the CRT screen. The specialist receives computations of the distance between the operator's shoulder and each control from which the specialist can determine which controls cannot be reached, a visual presentation of the operator's fingertip paths while performing a task from which the specialist can determine which component locations require unnecessarily long reaches or repetitive reaching, and estimates indicating the likelihood of error which may indicate the need for component relocation.

Procedure for Use: The HFE specialist must first learn to use HECAD and then assemble or generate the required data. The specialist does not have to learn a special language or code the data for entry. The specialist enters the data at the computer terminal by using a light pen on the CRT display or the CRT keyboard. The following data is entered: the name, size, type, activation time, activation reliability, and coordinates of each component; the corner coordinates of the panels; a list of the components in the order they are looked at or operated in each task sequence, the time to look at or operate, and any hardware warmup time.

The computer program reproduces on the CRT the display and control panels represented by outlines. The specialist lays out the components on the panels with a light pen on the CRT display or enters its number with the keyboard and positions crosshairs on the CRT display to indicate the location of the component. The computer program superimposes an asterisk on components which overlap or otherwise interfere.

When the design is complete, the specialist requests a reach analysis, a visual presentation of fingertip paths during a task sequence, or calculation of the probability of a task sequence being accomplished without error. The specialist uses this information to evaluate the design.

Advantages: 1) HECAD is one of the few techniques which provide interactive design layout capability.

2) HECAD is quick and easy for the HFE specialist to understand and use.

Limitations: HECAD requires an IBM 2250 computer terminal which has special function keys and an IBM graphics software package. HECAD has not yet been transferred from one computer facility to another.

Application Example: To validate the model, HECAD was used to evaluate redesign options for the B-52 Bombardment/Navigation station, and the results were used to direct further development of the model.

History and Source: HECAD was developed by Aerospace Medical Research Laboratory (Reference 25). The current version was completed in 1978. HECAD is implemented at AMRL, Wright-Patterson Air Force Base, Ohio.

Technical: HECAD is implemented on an IBM 370-155 and IBM 2250 CRT. The human reliability algorithms are derived from the American Institute of Research 1962 Human Reliability Data Store.

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25. Topmiller, D. A. and Aume, N. M., Computer Graphic Design for Human Performance, Proceedings 1978 Annual Reliability and Maintainability Symposium, pp. 385-388, 78 RM 006, 1978.

8.1.9 HOS (Human Operator Simulator)

Summary Description: HOS uses a computer to simulate an operater performing tasks in a system and the system responding to the operator's actions and to outside events.

HOS computes the time required to perform the tasks and how the system responds.

From the results of a HOS simulation, the HFE specialist can determine whether it is possible for the operator to perform all of the tasks in the available time. The specialist can also determine the effect on system performance if the operator cannot perform all the tasks.

In a HOS simulation the following subjects are not addressed: vision, reach, escape, percentage of operator population accommodated or excluded by crewstation dimensions, or crewstation compliance with specific military standards. HOS does not have a graphic display or interactive design layout capability and does not print out graphic illustrations.

When Used: HOS is used as soon as a preliminary design is developed to the extent that the required data is available, after the final design is completed but before hardware is built, or at other times in the system development cycle.

Product and Purpose: HOS provides a timeline in seconds of operator activities, the parts of the body used, and the hardware procedures being executed. The HFE specialists uses this data to evaluate designs. HOS is especially useful for evaluating time-critical mission situations in complex systems.

Procedure for Use: The HFE specialist must first learn to use HOS and then assemble or generate the required data. The specialist must learn the HOPROC language (which is similar to ordinary English) and then prepare HOPROC statements that describe the operator's tasks, the hardware changes that occur as the result of the operator's actions, and any hardware changes that occur as a result of independent events like movement of external targets or changes in the environment. The specialist also provides the names of all the displays and controls in the crewstation, indicates whether they are discrete or continuous and what any settings and scale factors are, and specifies control locations, sequence in which buttons are pressed, and other operating characteristics of the operator and the hardware.

Advantages: 1) Use of HOS forces the preparation of detailed task descriptions.

2) Data on human and system performance in hypothetical tactical situations can be obtained.

3) Different system configurations and operator strategies can be tested.

4) Complex system design problems can be examined.

Limitations: 1) HOS is expensive.

2) HOS requires considerable analytical skills from the HFE specialist and is time-consuming to use.

3) HOS has not yet been transferred from one computer facility to another.

Application Example: The Navy has fleet data on three configurations of the P-3C Antisubmarine Warfare aircraft. In one configuration the non-acoustic sensor operator's station did not have forward looking infrared (FLIR) capability, in another configuration the operator had a manually controlled FLIR system, and in the third configuration the operator had an automated FLIR system. Three simulations were run on HOS modeling the activities of the non-acoustic operator during a reconnaissance mission similar to those currently flown in the Mediterranean. The three simulations duplicated the three fleet configurations of the P-3C with respect to FLIR capability. Fleet experience had been that the operator was not able to use the manually controlled FLIR system to get the data for which the system had been intended and that in addition the FLIR system degraded the operator's performance of other tasks. The automated FLIR system solved these problems.

The HOS simulation results paralleled the fleet experience. Had HOS been available to evaluate each configuration before it was introduced to the fleet, the manual FLIR system could have been identified as unacceptable and not put into production.

History and Source: HOS was developed for the Naval Air Development Center by Analytics (Reference 26). The latest version was completed in 1975. HOS is implemented at NADC, Warminster, Pa..

Technical Details: The HOS computer programs are written in FORTRAN.

HOS contains a general model of human performance which the data entered by the user about the operator and the system of interest make system specific. There are micro models for short term memory, long term memory, information absorption, information recall, mental calculation, decision making, anatomy movement, control manipulation, and relaxation. The human model obtains information, remembers information, performs mental computations, makes decisions, moves hands, feet, and eyes, manipulates controls, and relaxes.

The human is modeled as a discrete, single channel information processor capable of rapidly multiplexing among several tasks and as an operator who does not make errors. The rationale of the errorless model is that a properly selected, trained, and motivated operator with sufficient time will not make errors and that real world errors are the result of time stress, improperly designed equipment, or an operator attempting to perform beyond capability.

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26. Strieb, M. I., Glenn, F. A., and Wherry, R. J., The Human Operator Simulator, Volume IX - HOS STUDY GUIDE, Analytics, Naval Air Development Center, 1978.

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21. Edwards, R. E., et al, Crewstation Assessment of Reach (CAR) User's Manual, D180-19321-1, Boeing Aerospace Company, Naval Air Development Center, April 1976.
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25. Topmiller, D. A. and Aume, N. M., Computer-Graphic Design for Human Performance, Proceedings 1978 Annual Reliability and Maintainability Symposium, pp. 383-388, 78 RM 066, 1978.

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APPENDIX A
ACRONYMS

BOEMAN	Computerized Mathematical Human Model
CAD	Computer Aided Design
CAFES	Computer Aided Function Allocation and Evaluation System
CAPE	Computer Accommodated Percentage Evaluation
CAR	Crewstation Assessment of Reach
CDRL	Contract Data Requirements List
CGE	Cockpit Geometry Evaluation
COMBIMAN	Computerized Biomechanical Man-Model
CUBITS	Criticality/Utilization/Bits of Information
DEP	Design Eye Point
DID	Data Item Description
DoD	Department of Defense
ERP	Eye Reference Point
FAM	Function Allocation Model
HE	Human Engineering
HECAD	Human Engineering Computer Aided Design
HFE	Human Factors Engineering
HOS	Human Operator Simulation
JANAIR	Joint Army Navy Aircraft Instrumentation Research Committee
NAVMAT	Chief of Navy Material

RFP	Request for Proporal
SECNAV	Secretary of the Navy
SOW	Statement of Work
WAM	Workload Assessment Model

3.2.2 Human Engineering in Equipment Detail Design. - During detail design of equipment, the human engineering inputs, made in complying with the analysis requirements of paragraph 3.2.1 herein, as well as other appropriate human engineering inputs, shall be converted into detail equipment design features. Design of the equipment shall meet the applicable criteria of MIL-STD-1472 and other human engineering criteria specified by the contract. Human engineering provisions in the equipment shall be evaluated for adequacy during design reviews. Personnel assigned human engineering responsibilities by the contractor shall participate in design reviews and engineering change proposal reviews of equipment end items to be operated or maintained by humans. Human engineering requirements during equipment detail design are specified in paragraphs 3.2.2.1, 3.2.2.2, 3.2.2.3 and 3.2.2.4 herein.

3.2.2.1 Studies, Experiments and Laboratory Tests. - The contractor shall conduct experiments, laboratory tests (including dynamic simulation per paragraph 3.2.2.1.2), and studies required to resolve human engineering and life support problems specific to the system. Human engineering and life support problem areas shall be brought to the attention of the procuring activity, and shall include the estimated effect on the system if the problem is not studied and resolved. These experiments, laboratory tests, and studies shall be accomplished in a timely manner, i.e., such that the results may be incorporated in equipment design. The performance of any major study effort shall require approval by the procuring activity.

3.2.2.1.1 Mockups and Models. - At the earliest practical point in the development program and well before fabrication of system prototypes, full-scale three-dimensional mockups of equipment involving critical human performance (such as an aircrew compartment, maintenance work shelter, or a command control console) shall be constructed. The proposed Human Engineering Program Plan shall specify mockups requiring procuring activity approval and modification to reflect changes. The workmanship shall be no more elaborate than is essential to determine the adequacy of size, shape, arrangement, and panel content of the equipment for use by humans. The most inexpensive materials practical shall be used for fabrication. These mockups and models shall provide a basis for resolving access, workspace and related human engineering problems, and incorporating these solutions into system design. In those design areas where equipment involves critical human performance and where human performance measurements are necessary, functional mockups shall be provided, subject to prior approval by the procuring activity. The mockups shall be available for inspection as determined by the procuring activity. Upon approval by the procuring activity, scale models may be substituted for mockups. Disposition of mockups and models, after they have served the purposes of the contract, shall be as directed by the procuring activity.

3.2.2.1.2 Dynamic Simulation. - Dynamic simulation techniques shall be utilized as a human engineering design tool when necessary for the detail design of equipment requiring critical human performance. Consideration shall be given to use of various models for the human operator, as well as human-in-the-loop simulation. While the simulation equipment is intended for use as a design tool, its potential relationship to, or use as, training equipment shall be considered in any plan for dynamic simulation.

3.2.2.2 Equipment Detail Design Drawings. - Human engineering principles and criteria shall be applied to equipment drawings during detail design to assure that the equipment can be efficiently, reliably and safely operated and maintained. The following drawings are included: panel layout drawings, communication system drawings, overall layout drawings, control drawings and other drawings depicting equipment important to system operation and maintenance by human operators. The approval of these drawings by the contractor shall signify that human engineering requirements are incorporated thereon and that the design complies with applicable criteria of MIL-STD-1472 and other human engineering criteria specified by the contract.

3.2.2.3 Work Environment, Crew Stations and Facilities Design. - Human engineering principles and criteria shall be applied to detail design of work environments, crew stations and facilities to be used by humans in the system. The approval of drawings, specifications and other documentation of work environment, crew stations and facilities by the contractor shall signify that human engineering requirements are incorporated thereon and that the design complies with applicable criteria of MIL-STD-1472 and other human engineering criteria specified by the contract. Design of work environment, crew stations and facilities which affect human performance, under normal, unusual and emergency conditions, shall consider at least the following where applicable:

a. Atmospheric conditions, such as composition, volume, pressure and control for decompression, temperature, humidity and air flow.

b. Weather and climate aspects, such as hail, snow, mud, arctic, desert and tropical conditions.

c. Range of accelerative forces, positive and negative, including linear, angular and radial.

d. Acoustic noise (steady state and impulse), vibration, and impact forces.

e. Provision for human performance during weightlessmess.

f. Provision for minimizing disorientation

g. Adequate space for man, his movement, and his equipment.

h. Adequate physical, visual, and auditory links between men and men, and men and their equipment, including eye position in relation to display surfaces, control and external visual areas.

i. Safe and efficient walkways, stairways, platforms and inclines.

j. Provisions for minimizing psychophysiological stresses.

k. Provisions to minimize physical or emotional fatigue, or fatigue due to work-rest cycles.

l. Effects of clothing and personal equipment, such as full and partial pressure suits, fuel handler suits, body armor, polar clothing, and temperature regulated clothing.

m. Equipment handling provisions, including remote handling provisions and tools when material and environment require them.

n. Protection from chemical, biological, toxicological, radiological, electrical and electromagnetic hazards.

o. Optimum illumination commensurate with anticipated visual tasks.

p. Sustenance and storage restraints (shoulder, lap and leg restraint systems, inertia reels and similar items) in relation to mission phase and control and display utilization.

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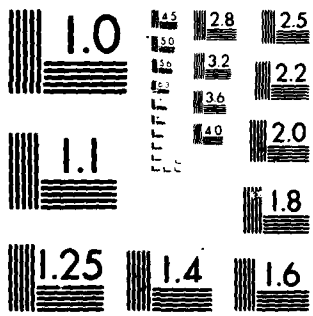

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DATA ITEM DESCRIPTION	2. IDENTIFICATION NO(S).	
	AGENCY	NUMBER
1. TITLE Human Engineering Dynamic Simulation Plan	DOD	DI-H-7052
3. DESCRIPTION/PURPOSE This plan describes the contractor's intended use of dynamic simulation techniques in support of human engineering analysis, design support and test and evaluation.	4. APPROVAL DATE 1 June 1979 5. OFFICE OF PRIMARY RESPONSIBILITY ARMY/MIRADCOM 6. DDC REQUIRED 8. APPROVAL LIMITATION	
7. APPLICATION/INTERRELATIONSHIP This DID is related to DI-H-7059, Human Engineering Progress Report. This DID replaces UDI-H-21388. This DID is primarily applicable to work tasks delineated in paragraph(s) 3.2.2.1.2 of MIL-H-46855B.	9. REFERENCES (MANDATORY AS CITED IN BLOCK 10) MIL-H-46855B MCSL NUMBER(S)	

10. PREPARATION INSTRUCTIONS

10.1 Content Requirements. The plan shall consist of the following information:

1) Rationale and General Description. The need for a dynamic simluation program shall be described. The overall simulation concept shall be described. Benefits to be derived from dynamic simulation shall be stated. The interrelationships between dynamic simulation and other human engineering analysis, design support and test and evaluation techniques shall be described.

2) Techniques. Each dynamic simulation technique and procedure proposed by the contractor shall be fully described. Rationale for the selection of techniques shall be given. The specific contributions of each technique to human engineering anslysis, design support and test and evalution shall be stated. Previous efforts conducted by the contractor or others to validate each proposed technique shall be described, including a discussion of results.

3) Activities. The intended use of each dynamic simulation technique shall be described with regard to each of the following:

a) human performance and workload analysis, test and demonstration.

b) system design development, test and demonstration.

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10. PREPARATION INSTRUCTIONS (continued)

c) system effectiveness studies, tactics development and verification

d) development and verification of operator skill, knowledge and other training data.

e) operator procedures development and verification, including degraded mode and emergency procedures.

f) training equipment design and verification studies

g) development and verification of technical publications

4) Organization and Personnel. The plan shall identify and describe the contractor organizational elements responsible for executing the Human Engineering Dynamic Simulation Plan. Structural definition shall include the number of proposed personnel, level of effort (in man-months) and the functions of key personnel. The relationships between responsible organizational elements shall be described. The authority delegated to each element shall be stated in explaining the relationship.

5) Schedule. A detailed schedule shall be prepared. Compatibility between the simulation schedule and the release of program analyses, design and test products for each area of utilization described in paragraph 3) above shall be described. Facility and special requirements (per paragraph (7) below) shall be indicated on the schedule.

6) Data. Data acquisition procedures and techniques, types of qualitative and quantitative data to be obtained and data analysis techniques shall be fully described. The plan shall state that simulation results shall be described in Human Engineering Progress Reports (DI-H-7059).

7) Facilities and Special Requirements. Dynamic simulation facilities shall be described. Any requirements to utilize government facilities, models, data or other government property shall be identified. If the contractor requires participation by government personnel (e.g., as subjects in simulation studies), appropriate information shall be provided - such as number and qualifications of personnel, desired level of participation and schedule of participation.

8) Scenarios and Mission Descriptions. The scenarios and missions to be simulated shall be described. Information on mission objectives, geography, threats, weather conditions, or any other data relevant to system simulation shall be presented.

10.2 Format Requirements. The Human Engineering Dynamic Simulation Plan shall be prepared in contractor format.

*U.S. GOVERNMENT PRINTING OFFICE: 1979-603-022/0030

DATA ITEM DESCRIPTION	2. IDENTIFICATION NO(S).	
	AGENCY	NUMBER
1. TITLE Human Engineering Design Approach Document-Maintainer	DOD	DI-H-7057

3. DESCRIPTION/PURPOSE

This document provides a source of data to evaluate the extent to which equipment having an interface with maintainers meets human performance requirements and human engineering design criteria.

4. APPROVAL DATE

1 June 1979

5. OFFICE OF PRIMARY RESPONSIBILITY

ARMY/MIRADCOM

6. DDC REQUIRED

8. APPROVAL LIMITATION

7. APPLICATION/INTERRELATIONSHIP

This DID replaces DI-H-2108 and UDI-H-21385.

This DID is primarily applicable to work tasks delineated in paragraph(s) 3.2.1.2, 3.2.1.3, 3.2.1.4, and 3.2.2 of MIL-H-46855B.

9. REFERENCES (MANDATORY AS CITED IN BLOCK 10)

MIL-H-46855B
MIL-STD-1472

MCSL NUMBER(S)

10. PREPARATION INSTRUCTIONS

10.1 General. The Human Engineering Design Approach Document - Maintainer (HEDAD-M) shall be prepared which describes the characteristics, layout, and installation of all equipment having a maintainer interface (excluding depot level maintenance actions); it shall also describe maintainer tasks associated with the equipment. The HEDAD-M shall describe the extent to which the requirements of MIL-STD-1472 and other applicable human engineering documents specified in the contract have been incorporated into the design, layout, and installation of equipment having a maintainer interface. Maintainer task analysis results shall be presented as part of the rationale supporting the layout, design and installation of the equipment. The requirement for this information is predicated on the assumption that, as analytic and study information, it is developed sufficiently early to influence the formulation of other system data such as maintenance allocation charts, special repair parts/tool lists, LSAR data. If the program has progressed to the point where the required data is available through other reporting media, such as those noted above, they shall not be duplicated but shall be referenced or appended to the HEDAD-M along with appropriate supplementary information fulfilling the intent of this provision.

10.2 Content Requirements. The HEDAD-M shall consist of the following information:

1) List of each item of equipment having a maintainer interface at the Organizational and Field/Intermediate Maintenance Activity (IMA) level, a brief statement

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10. PREPARATION INSTRUCTIONS (continued)

of the purpose of each item of equipment and the types of maintenance required on each item of equipment (e.g., troubleshoot, remove, inspect, test, repair).

2) List of specifications and drawings approved by human engineering at the time of HEDAD-M preparation. The list shall also address documents where human engineering approval is planned.

3) Description of system equipment, emphasizing human engineering design features. The following aspects of equipment shall be described:

a) Layout of System Equipment. (1) The location and layout of all system equipment requiring maintenance shall be described with emphasis on human engineering features which facilitate maintenance. Equipment located in areas assessed through common doors, panels, openings, etc., shall be indicated. (2) The location of each item of equipment shall also be noted in terms of three-dimensional space (i.e., X, Y, and Z coordinates); the reference point for each item of equipment shall be its center as viewed by the maintainer while gaining access to the equipment.

b) Design of Equipment. The design of each item of equipment shall be described with emphasis on human engineering features which facilitate maintenance such as handles, self-test capability, labeling, connector spacing and keying.

c) Installation of Equipment. The installation of each item of equipment shall be described with emphasis on human engineering features which facilitate maintenance such as fasteners, clearances, relationship between accessibility and failure rate (or scheduled maintenance frequency) of each item of equipment and visual access afforded.

4) Rationale. The specific considerations of equipment maintenance requirements (e.g., frequency, criticality, equipment failure rate), maintainer requirements (e.g., personnel selection, training and skills), maintainer task requirements, environmental considerations, safety and limitations imposed by the procuring activity or state-of-the-art shall be described. The bases for reaching specific design, layout and installation decisions shall be presented (e.g., MIL-STD-1472 criteria, other human engineering requirements specified in the contract, human engineering studies, trade-off analyses, mock-up results and human engineering test results).

5) List of special tools, support equipment, job aids/devices required for maintenance of each item of equipment.

6) Maintainer task analysis results presented as part of the rationale supporting layout, design, and installation of item of equipment. Maintainer task analyses shall consist of the following:

10. PREPARATION INSTRUCTIONS (continued)

task number, task title, task frequency (for scheduled maintenance actions) or estimated task frequency (based on equipment mean-time-between-failure for unscheduled maintenance actions), data source used (e.g., drawing number, sketch number, development hardware, actual production equipment), detailed task sequence (see paragraph 6.2.5 of MIL-H-46855B), support equipment required, tools required, job aids required, estimated task time, estimated personnel requirements (e.g., number of personnel required, skills and knowledge required) and human engineering considerations which reflect specific human engineering requirements incorporated into the design (e.g., maintainer fatigue, potential hazards, safety or protective clothing/equipment required or recommended, access problems, maintainer communication requirements, special task sequence requirements, labeling). As applicable, the following types of maintainer tasks shall be addressed by task analyses: remove/replace, trouble-shoot (fault location), repair, adjust, inspect, service and test. Critical tasks (see paragraph 6.2.1 of MIL-H-46855B) shall be clearly identified.

7) Narrative which provides rationale for any need to deviate from, or take exception to, MIL-STD-1472 or other contractual item human engineering requirements.

8) Two sketches, drawings or photograph of each of equipment having a maintainer interface. Each item of equipment shall be depicted, a) by itself from top, front and side (three-view trimetric or exploded trimetric view) and b) installed as the maintainer would normally view it during maintenance.

9) Sketches, drawings or photograph of each item of equipment being considered as alternatives to the selected, or baseline design. Sketches, drawings or photographs of alternative equipment installations or layouts which exist at the time of HEDAD-M preparation.

10) Description of design, installation or layout changes which have been made since the last HEDAD-M submission.

10.3 Format and Data Organization Requirements. The HEDAD-M be prepared in contractor format except that information shall be presented in two major parts:

1) Information pertaining to maintenance actions performed at the Organizational Level.

2) Information pertaining to maintenance actions performed at the Field/IMA level.

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DATA ITEM DESCRIPTION

2. IDENTIFICATION NO(S).

AGENCY	NUMBER
DOD	DI-H-7056

1. TITLE

Human Engineering Design Approach Document-Operator

3. DESCRIPTION/PURPOSE

This document provides a source of data to evaluate the extent to which equipment having an interface with operators meets human performance requirements and human engineering criteria.

4. APPROVAL DATE

1 June 1979

5. OFFICE OF PRIMARY RESPONSIBILITY

ARMY/MIRADCOM

6. DDC REQUIRED

8. APPROVAL LIMITATION

7. APPLICATION/INTERRELATIONSHIP

This DID replaces DI-H-2107, DI-H-3261A, DI-H-4605, UDI-H-21272 and UDI-H-21385.

This DID is primarily applicable to work tasks delineated in paragraph(s) 3.2.1.2, 3.2.1.3, 3.2.1.4, and 3.2.2 of MIL-H-46855B.

9. REFERENCES (MANDATORY AS CITED IN BLOCK 10)

MIL-H-46855B
MIL-STD-1472

MCSL NUMBER(S)

10. PREPARATION INSTRUCTIONS

10.1 General. The Human Engineering Design Approach Document - Operator (HEDAD-O) shall be prepared which describes the layout, detail design and arrangement of crew station equipment having an operator interface; it shall also describe operator tasks associated with the equipment. The HEDAD-O shall describe the extent to which the human performance requirements, MIL-STD-1472 and other applicable human engineering documents specified in the contract have been incorporated into the layout, design and arrangement of equipment having an operator interface. Operator task analysis results shall be presented as part of the rationale supporting the layout, design and integration of crew station equipment.

10.2 Content Requirements. HEDAD-O shall consist of the following crew station and operator-related information:

1) List of each item of equipment having an operator interface and a brief statement of the purpose of each item of equipment. Separate lists shall be provided for each operator's station.

2) List of specifications and drawings approved by human engineering at the time of HEDAD-O preparation. When contractually required to prepare and submit the HEDAD-O early in the development process, the list shall also address documents where human engineering approval is planned.

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10. PREPARATION INSTRUCTIONS (continued)

3) Description of the crew station(s), emphasizing human engineering design features. The following aspects of the (each) crew station shall be described:

a) Layout and Arrangement. One sketch, drawing or photograph of the (each) crew station shall be provided. These sketches, drawings or photographs shall contain operator and equipment related reference points (e.g., operator eye position, seat reference point) and scale. One sketch, drawing or photograph of each item of crew station equipment shall be provided; the point of reference shall be normal to the item of equipment and scale shall be indicated.

b) Controls and Displays. The layout and detail design of each control/display panel (or control/display areas independent of panels) shall be described (e.g., phospher type, brightness, resolution, contrast, color or other coding, control/display ratio, control force and range characteristics). Display symbology, display formats and control/display operation logic shall be described with regard to intended use by the operator(s).

c) Operator Vision. Operator vision to crew station items of equipment shall be described using the operator's normal eye position(s) as the point of reference. When applicable, operator external vision shall also be described using the operator's normal eye position(s) as the point of reference; extent of external vision shall be related to system mission requirements.

d) Environmental Factors. Operator life support systems, protective clothing and equipment, noise, vibration, radiation, temperature, ambient illumination, climatic effects and other relevant environmental parameters shall be described.

e) Ingress/Egress. Normal and emergency ingress and egress provisions/procedures shall be described.

f) Crew Station Lighting. Lighting characteristics and lighting control systems shall be described.

g) Crew Station Signals. Warning, caution and advisory signals shall be described with regard to signal characteristics, signal meaning, signal consequences, operator procedures, cause of signal activation and crew control over signal characteristics.

h) Operator Posture Control. Seating, restraint systems and other postural control techniques shall be described.

i) Communications Systems and Communications Systems Control.

j) Special design, layout or arrangement features if required by mission or system environment.

10. PREPARATION INSTRUCTIONS (contined)

k) Multiple operator stations design, if applicable. Rationale for number of operators, arrangement of operators and allocation of functions to the operators shall be described.

4) Geometric layout of the crew station(s). Crew station geometry shall be described using the seat reference point or operator's eye position(s) as a reference point. The position of each control, display, panel, etc., shall be described in terms of three-dimensional space (X, Y, Z coordinates); operator eye position shall be described in terms of system design coordinates or as zero (X), zero (Y) and zero (Z). The center of each panel, display, control, etc., shall be used as the equipment point of reference. True angle to vision to each item of equipment shall also be shown.

5) Rationale for human engineering design, layout and arrangement of each item of crew station equipment having an operator interface. The specific considerations of system mission (or system function): equipment operation; operator selection, training and skill requirements; operator task performance requirements; and limitations imposed on designs by the procuring activity or state-of-the-art shall be described. The basis for reaching specific design, layout and arrangement decisions shall be presented (e.g., MIL-STD-1472 criteria, other human engineering requirements specified in the contract, system engineering analyses, systems analyses, human engineering studies, trade-off analyses, mock-up results, simulation results and human engineering test results).

6) Operator task analysis (see paragraph 6.2.5 of MIL-H-46855B) results shall be presented as part of the rationale for crew station design, integration and layout. The follcwing shall also be described: methodology used to generate task analysis results (e.g., paper and pencil, computer-based simulation, dynamic simulation); system mission(s), function(s) or other exogenous information used to "drive" the task analysis; human performance data (i.e., time and error) against which task analysis results are compared: and operator assumptions (e.g., level of skill, training). Critical tasks (see paragraph 6.2.1 of MIL-H-46855B) shall be clearly identified.

7) Narrative which provides rationale for any need to deviate from, or take exception to, MIL-STD-1472 or other contractual human engineering documents.

8) Sketches, drawings or photographs of each item of equipment being considered as alternatives or changes to the selected (baseline) crew station design.

9) Design, arrangement or layout changes made since the last HEDAD-O preparation shall be described.

10.3 Format Requirements. Contractor format shall be utilized.

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